VON KARMAN CENTER

SNAP-8 DIVISION

ENGINEERING SUPPORT DOCUMENTATION FOR THE SNAP-8 TURBINE ALTERNATOR ASSEMBLY (LeRC UNIT 4/1)

VOLUME IB

TAA DESIGN AND REQUIREMENTS

A REPORT TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

REPORT NO. 2954 / NOVEMBER 1965 / COPY NO.

AEROJET GENERAL TIRE GENERAL

AEROJET-GENERAL CORPORATION

AZUSA, CALIFORNIA

ENGINEERING SUPPORT DOCUMENTATION FOR THE

SNAP-8 -1 TURBINE ALTERNATOR ASSEMBLY
(LeRC UNIT 4/1)

VOLUME IB: TAA DESIGN AND REQUIREMENTS

A REPORT TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

REPORT NO. 2954 NOVEMBER 1965

Volume I, TAA Design and Requirements, is bound as two separate units, Volume IA and Volume IB. Volume IA includes pages I-1 through III-157 and Volume IB includes pages IV-1 through VI-8.

AEROJET-GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

IV. SUPPORTING DESIGN ANALYSES

This section consists of the following four sections:

A. PIPING LOADS

1. A. Levitsky, Piping Load Stress Analysis - MLA, SL-1, AGC Technical Memorandum No. 340:64-1-185, 24 February 1964.

2. A. Levitsky, Flange Stress Analysis, PCS-1, PCS-2, AGC Technical Memorandum No. 340:64-1-186, 30 June 1964.

3. A Levitsky, Component Piping Connection Loads - MLA, SL-1, AGC Technical Memorandum No. 340:64-1-187, 5 February 1964 and Supplement A, 17 December 1964.

B. MOUNTING TRUNNIONS

1. TAA Trunnion Design and Analysis, PCS-1, AGC Memorandum 340-64-0102, 12 September 1964.

C. SPLINE DRIVE

1. TAA Drive Spline, AGC Memorandum 4832-64-367, 2 December 1964.

D. TAA CRITICAL SPEED

1. C. S. Mah, TAA Critical Speed, AGC Technical Memorandum No. 395:64-2-253, 5 November 1964.

TM 340:64-1-185

PIPING LOAD AND STRESS ANALYSIS - MLA, SL-1

Sections of following TM Applicable to Turbine Alternator Assembly

10-047-009 (REV. 6/63)

DIVISION SNAP-8
TM 340:64-1-185
DATE 24 February 1964
W.O. 0743-02-2000

TECHNICAL MEMORANDUM

AUTHOR(S): A. Levitsky

TITLE: PIPING LOAD AND STRESS ANALYSIS - MLA, SL-1

ABSTRACT

This report presents the stress and load analysis of all the piping that form a part of the Mercury Loop Assembly - SL-1. The analysis was performed in order to design an efficient, safe piping system that would be compatible with the dimensional limitations of the SL-1 assembly.

The thermal expansion effects were treated separately from the "dead load" (pressure and gravity load) effects. Stresses from these two effects were not combined, and margins of safety were calculated separately. This approach conforms to the requirements of ASA B31.1 Code for Pressure Piping. Allowable stresses are as listed in the above mentioned code.

"Dead load" stress analyses were not performed in cases where effects were negligible, or could be made so by adequately supporting the piping system. In all cases, the final design resulted in a piping system with positive margins of safety for both "dead load" and thermal expansion stresses.

APPROVED:
DEPARTMENT HEAD P. I. Wood
P. I. Wood

COPY NO. 39
PAGES:

TABLE OF CONTENTS

I. INTRODUCTION

A piping system is a space structure into which stresses and strains are introduced by initial fabrication and assembly, the effects of gravity and pressure, and exposure to temperature variations. Under special circumstances, there may also be effects due to dynamic loadings resulting from pressure surges or external force excitation. Fabrication and erection effects have not been considered in this analysis, since all piping will be fitted, cut, and welded to the flanges at final assembly minimizing the effects of unintended "cold-spring." Dynamic effects have also been neglected as there are no significant external or internal vibration or shock loadings expected in the SL-1 ground test system.

Gravity stresses were determined with the aid of a programmed computer solution available through the Aerojet-General Computer Science Division. The weight of the piping, insulation and working fluid (except if a gas) were taken into account in the analysis. The weight was treated as a number of "lumped" concentrated effects rather than as a distributed load in order to accommodate the limitations of the computer program.

Pressure stresses were calculated using the simplified formula for hoop stress in a thin walled cylinder. Where the gravity load was significant, the longitudinal pressure stress was also determined in order to calculate the maximum principal stress due to the "dead load" effects.

Thermal expansion stresses were computed using a programmed piping solution. The solution takes into account the effects of intermediate and terminal restraint movements, as well as the thermal expansion of the piping itself. Bending and torsional deflections are considered, but second order effects such as axial and shear deflections are neglected. The effects of increased flexibility and stress intensification at the piping bends also form part of the programmed solution. For the sake of simplicity, the piping geometry was assumed to be orthogonal with no inclined elements.

II. CONCLUSIONS AND RECOMMENDATIONS

A. The method used in this analysis is conservative since it is based on the ASA Code for Pressure Piping. The procedure and data presented in the Code are based on 100,000 hours of operation and a minimum of 7,000 cycles, which is considerably beyond the expected use. The SL-1 Mercury Loop piping assemblies all have positive margins of safety, and while conservative, are adequate for the ground test system.

B. More quantitative data are required on the expected corrosion rates in the piping, particularly on the turbine mercury inlet line. This data will enable the piping to be designed with reduced wall thickness, resulting in decreased weight and lower loads on the component piping connections.

C. It would be advantageous to review the total expected load-cycle history of the piping systems (thermal, pressure, acceleration, and dynamic) in order to determine a more directly applicable set of allowable stress criteria.

D. Experience indicates that the end loads, i.e., the loads that are exerted on the connecting equipment, are usually critical rather than the pipe stress. In order to reduce the complexity and weight of the piping, therefore, the component piping connections should be reinforced as required, so that they can absorb the loads resulting from the piping being stressed to its maximum allowable stress.

III. SYMBOLS

c	outside radius of pipe (inches)
CA	corrosion allowance (inches)
Di	inside diameter of pipe (inches)
Do	outside diameter of pipe (inches)
E	modulus of elasticity (psi)
Fx	force in the x direction (pounds)
Fy	force in the y direction (pounds)
Fz	force in the z direction (pounds)
h	flexibility characteristic
I	area moment of inertia (in^4)
i	stress intensification factor
M_B	bending moment (in-lbs, or ft-lbs)
M_T	torsional moment (in-lbs, or ft-lbs)
M_x	moment about the x axis (ft-lbs)
My	moment about the y axis (ft-lbs)
Mz	moment about the z axis (ft-lbs)
P	pressure (psi)
r_m	mean radius of pipe (inches)

R	radius of piping bend (inches)
S_1	maximum resultant principal stress (psi)
S_{ALL}	allowable stress range for thermal expansion (psi)
S_C	allowable stress at room temperature (psi)
S_E	equivalent stress to be compared to the allowable thermal expansion stress range (psi)
S_H	allowable stress at operating temperature (psi)
t	minimum corroded pipe wall thickness (inches)
t_n	nominal pipe wall thickness (inches)
Wi	weight of insulation (lbs/ft)
Wp	weight of pipe (lbs/ft)
W_{HG}	weight of mercury in pipe (lbs/ft)
Z	section modulus (in^3)
α	linear coefficient of expansion (in/in-°F)
δ_x	movement in the x direction (inches)
δ_y	movement in the y direction (inches)
δ_z	movement in the z direction (inches)
ρ	specific weight (lbs/in^3)
σ_B	bending stress (psi)
σ_L	maximum longitudinal stress due to pressure and weight (psi)
σ_p	circumferential pressure stress (psi)
τ	torsional shear stress (psi)
θ_x	rotation about the x axis (radians)
θ_y	rotation about the y axis (radians)
θ_z	rotation about the z axis (radians)

Computer Notations

DELTA X (DX)	deflection in the X direction (inches)
DELTA Y (DY)	deflection in the Y direction (inches)
DELTA Z (DZ)	deflection in the Z direction (inches)
EE	linear coefficient of thermal expansion (in/in-°F.)
EH	modulus of elasticity (psi)

PHI X	rotation about the X axis (degrees)
PHI Y	rotation about the Y axis (degrees)
PHI Z	rotation about the Z axis (degrees)
O.D.	outside diameter
POIS	Poissons ratio
SIF	stress intensification factor
TH	pipe wall thickness (inches)
WT	weight of pipe, insulation, and fluid (lbs/ft)

IV. DISCUSSION AND RESULTS

The types of loadings which pipings systems may experience may be broken up into two distinct categories.

A. Those representing the application of external forces, which if excessive, would cause failure independent of strain.

B. Those representing the application of a finite external or internal strain generally introduced through thermal expansion.

Individual loadings may be:

1. Present during only normal operation
2. Existent throughout service life
3. Short duration (startup and shutdown conditions)
4. Abnormal conditions (emergency)

When determining allowable stress values, it is logical to distinguish between primary, secondary, and localized stresses.

Primary stresses are a result of axial, shear or bending loads necessary to satisfy the laws of static equilibrium. Pressure, gravity loading, and thermal loading are some examples of forces causing primary stresses. In general, the level of these primary stresses is a measure of the ability of the piping system to withstand the loadings safely.

Secondary stresses in a pipe may result from differential radial deflection in a pipe wall. This may result from a radial temperature gradient in the pipe. These stresses do not cause direct failure in a ductile material upon a single load application. If above the yield point, yielding occurs with accompanying redistribution and reduction of the thermal stresses. If the loading is cyclic, however, a local strain range is established equivalent to the full original magnitude, thus constituting a potential source of fatigue failure.

Localized stresses in a pipe or vessel decrease rapidly and disappear within a short distance from the origin. The stresses induced in a vessel at a piping connection is an example of this type stress. The Piping Code treats the case of localized stress at a branched piping connection by defining a stress intensification factor. This factor is based upon the geometry at the joint and is used to multiply the nominal bending stress at a piping junction to obtain the working stress.

The stress analysis of piping is based upon two separate design criteria. One is the "code allowable stress" (S_H), values of which are listed in the "Code for Pressure Piping," and the second is the "allowable stress range," which is derived from the "code allowable stress." In the lower temperature ranges this allowable stress is the lesser of one-third of the minimum tensile strength or 60 per cent of the minimum 0.2 per cent yield strength. At higher temperatures, where creep becomes significant, the allowable stress is equal to 100 per cent of the stress to produce .01 per cent creep in 1,000 hours or 100 per cent of stress to produce rupture at the end of 100,000 hours, whichever is less.

The Piping Code defines an "allowable stress range" equal to ($1.25\ Sc + 0.25\ S_H$). This "allowable stress range" has been chosen with the objective of providing a minimum of 7,000 thermal cycles of operation without failure. It is applicable to ductile materials, and is a measure of the permissible strain range in a cycle of operation. The strain induced in a pipe is a function of the total effects of pressure, gravity load, fabrication loads and thermal expansion. As the pipe approaches operation temperature the yield stress drops and plastic flow occurs with accompanying reduction in stresses. For moderate temperature piping, the adjustment of thermal strain between the hot and cold condition occurs during the initial cycle and depends on the magnitude of the total stress. For higher temperatures, where creep occurs, strain adjustment continues until the combined stress at operating temperature reduces to the relaxation limit. The strain range per cycle, however, does not change and this forms the basis for the "allowable stress range," as defined in the Piping Code. If stresses are kept below the "allowable stress range," the adjustment of stress is such that plastic flow due to expansion effects does not occur with each cycle, except possibly in the initial operating period. This occurs only once, however, and should have no effect on the fatigue life.

In general, the thermal expansion in a space system will result in three forces and three moment components at each end point. For partial fixity, the number of force and moment components is reduced and is equal to the number of degrees of restraint. These end reactions are generally calculated using the Theorem of Castigliano or similar strain energy theorems. The moments and forces at any section may then be calculated using the laws of statics. Stresses at any section can then be computed utilizing the section modulus of the pipe.

The Piping Code contains the following equation for the combination of stresses due to thermal expansion:

$$S_E = \sqrt{\sigma_B^2 + 4\tau^2}$$

This combined stress ($_E$) is based on the Maximum Shear Theory, and should be kept below the Code "allowable stress range." As a separate criteria, the Code establishes that the maximum principal stress due to pressure weight and other sustained loadings must be maintained less than the "Code allowable stress" at operating temperature (S_{II}). The maximum principal stress at the outside fiber may be written as:

$$S_1 = 0.5\left[\sigma_L + \sigma_P + \sqrt{4\tau^2 + (\sigma_L - \sigma_P)^2}\right]$$

The Piping Code requires that the stress at branded connections be adjusted to include the effects of stress intensification. The boiler mercury inlet and the condenser mercury outlet lines contain fabricated tee branches, and the nominal stress at these locations were increased to obtain working stresses as per Code requirements. Instrumentation connections will be reinforced with saddles, however, and the effects of stress intensification at these locations were neglected.

All piping welds contained in the SL-1 Mercury Loop Assembly are 100% radiographically inspected. As per ASME Pressure Vessel Code data, a weld efficiency of 100% was assumed for this type of design.

I. FORMULA

$$\sigma_p = \frac{pD_o}{2t}$$

II. DATA

	DESIGN PRESSURE (FLIGHT) PSIG	DESIGN TEMP. ^oF.	TUBE SIZE in.	WALL THICKNESS in.	MINIMUM WALL THICKNESS in.	CORROSION ALLOWANCE in.	MINIMUM CORRODED THICKNESS (t) in.	σ_p (PSI)	HOT ALLOWABLE STRESS (S_H)	MARGIN OF SAFETY
Boiler NaK Inlet	49	1298	2.000	0.049	0.044	0.010	0.034	1440	4000	+ 1.78
Boiler NaK Outlet	46	1100	2.000	0.049	0.044	0.010	0.034	1350	10400	+ 6.70
Boiler Hg Inlet	(370 (10^{-2}MM Hg	515 1300	0.750	0.035	0.031	0.010	0.021	6600	14500	*
Turbine Hg Inlet (Turbine Simulator Hg Inlet)	300	1300	1.750	0.120	0.108	0.010	0.098	2700	4000	*
Condenser NaK Inlet	56.4	496	2.000	0.049	0.044	0.010	0.034	1650	17200	+ 9.40
Condenser NaK Outlet	44	665	2.000	0.049	0.044	0.010	0.034	1290	17050	+ 12.20
Condenser Hg inlet	15.5	680	4.250	0.063	0.056	0.010	0.046	710	13400	+ 17.90
Condenser Hg Outlet	10^{-2}MM Hg to 12 psia	505	1.000	0.035	0.031	0.010	0.021	360	14500	+ 39.00
Mercury Pump Hg Inlet	10^{-2}MM Hg to 12 psia	505	1.000	0.035	0.031	0.010	0.021	360	14500	+ 39.00
Mercury Pump Hg Outlet	370 10^{-2}MM Hg	515 1300	0.75	0.035	0.031	0.010	0.021	6600	14500	+ 1.19
Flow Control Valve Hg Inlet	370 10^{-2}MM Hg	515 1300	0.75	0.035	0.031	0.010	0.021	6600	14500	+ 1.19

III. NOTES

1. Corrosion allowances are estimated.
2. Allowable stresses are as per ASME Boiler Code
3. * Where margin of safety is not shown, gravity load stress is considered significant, and maximum principal stress was calculated (Ref. ~~P.15~~ P.24)

01-071-002

QUADRILLE WORK SHEET

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

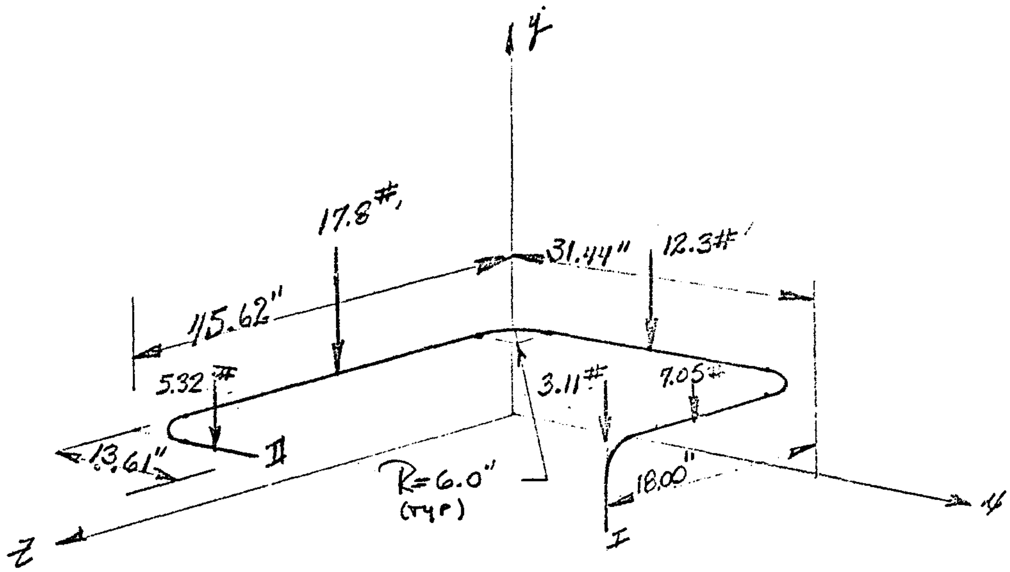
SUBJECT: TURBINE INLET (E) SC-1 PIPING FLEXIBILITY CALC. (GRAVITY LOAD)

BY

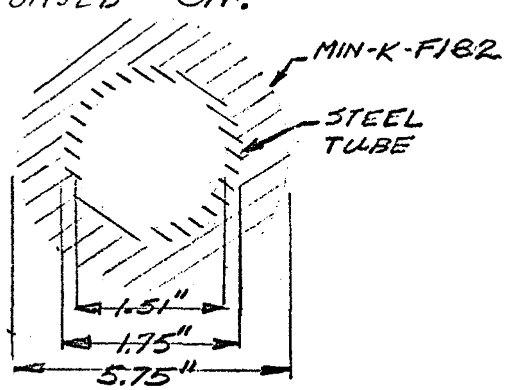
PAGE 8 OF PAGES

DATE

WORK ORDER



BASED ON:



$$W\ (LB/FT) = W_i + W_p = 2.62 + 2.08 = 4.70\ \frac{LB}{FT}$$

FIXITY AT BOTH ENDS

$D_o = 1.750''$

WALL THICKNESS = 0.035"

PIPING FLEXIBILITY ANALYSIS - L03812

TURBINE INLET -- GRAVITY LOAD -- CASE 5

DEFLECTIONS AT RESTRAINTS HAVING KNOWN FORCES

RESTRAINT	NO. 2	-0.00000
RESTRAINT	NO. 3	-0.00513
RESTRAINT	NO. 4	-0.02534
RESTRAINT	NO. 5	-0.01810
RESTRAINT	NO. 6	-0.00001

TOTAL MOMENTS AND FORCES ON ORIGIN

MX	MY	MZ	FX	FY	FZ
~~10.52~~ -25.6	~~0.09~~ 0.22	~~6.04~~ 14.7	~~0.07~~ 0.17	~~9.92~~ -24.1	~~0.12~~ 0.29

REACTIONS OF PIPE ON ANCHORS

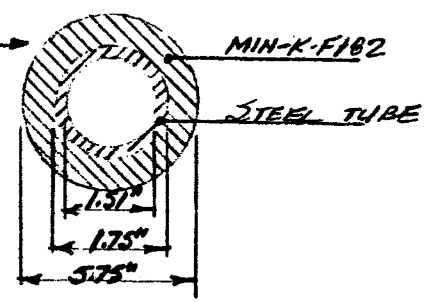
END	MX	MY	MZ	FX	FY	FZ
2	~~11.58~~ -28.2	~~0.32~~ 0.78	~~6.70~~ 16.3	~~0.07~~ -0.17	~~0.06~~ -21.6	~~0.12~~ -0.29

POINT	STRESS	PHI X	PHI Y	PHI Z	DELTA X	DELTA Y	DELTA Z
0	750.73	0.000	0.000	0.000	0.000	0.000	0.000
1	752.17	-0.004	0.000	0.002	-0.000	-0.000	-0.000
2	546.13	-0.039	0.003	0.022	-0.001	-0.003	-0.002
3	454.99	-0.042	0.003	0.027	-0.001	-0.005	-0.002
4	411.86	-0.045	0.003	0.032	-0.002	-0.007	-0.002
5	199.59	-0.050	0.004	0.048	-0.002	-0.017	-0.002
6	89.62	-0.049	0.004	0.050	-0.002	-0.025	-0.001
7	123.23	-0.049	0.004	0.046	-0.002	-0.034	-0.000
8	146.55	-0.050	0.003	0.039	-0.002	-0.033	0.000
9	159.41	-0.052	0.003	0.029	-0.001	-0.018	0.000
10	530.68	-0.039	0.002	0.018	-0.000	-0.004	0.000
11	808.77	-0.005	0.000	0.002	-0.000	-0.000	0.000
12	810.33	-0.003	0.000	0.001	-0.000	-0.000	0.000
13	828.20	-0.000	-0.000	0.000	0.000	0.000	-0.000

NOTES:

a) ABOVE ORIGINAL LOADS & STRESSES (IN TYPE-PRINT) ARE BASED ON O.D. = 1.75"; W.T. = 0.095", & W = 1.49 #/FT.

b) CHANGED FIGURES (IN INK) ARE BASED ON →



c) STRESSES HAVE NOT BEEN ADJUSTED, SINCE THE DIFFERENCES WOULD BE NEGLIGIBLE.

TEST NO. 5 OKAY

SIMULTANEOUS EQUATION CONSTANTS AND CHECK		EQUATION RESULTS
0.01	0.01	-0.00
-0.46	-0.46	-0.01
116.48	116.48	-0.03
466.69	466.69	-0.02
627.21	627.21	-0.00
-120.34	-120.34	-8.72
-5.18	-5.18	0.09
-114.42	-114.42	-24.33
-65.82	-65.82	0.07
115.33	115.33	8.86
80.14	80.14	0.12

```
 4327     1.317556  1     4328    6.804507  0     4329   -9.659822  0     4330    3.218276  1     4331    4.747001  0
 4332     2.546453  1     4333    3.015104 -5     4334               0     4335    2.000000  0     4336    3.000000  0
 4872     8.304133  0     4873               0     4874    5.215406 -8     4875    3.455206 -8     4876   -7.187994  0
 4877    -5.124178  0     4878    8.134778  0     4879    1.705473 -1     4880    7.676480  0     4881               0
 4882    -9.871655  0     4883    8.120538  0     4884    5.051220  0     4885    1.027096  1     4886   -4.470348 -8
 4887     1.317556  1     4888    6.804507  0     4889   -9.659821  0     4890    3.218276  1     4891    4.747000  0
 4892     2.546453  1     4893               0     4894               0     4895               0     4896   -8.381957-10

                                           SHAPE COEFFICIENTS DO NOT CHECK
THE FOLLOWING INDICATORS ARE ON       DIVIDE CHECK
INDEX A HAS  7932 OR   260      INDEX B HAS      0 OR      0      INDEX C HAS  7690
 SENSE LIGHTS ON    NONE       SENSE SWITCHES ON    NONE
 4312     1.108180  1     4313               0     4314   -1.705472 -1     4315   -1.129875 -1     4316   -3.156734  0
 4317    -6.964378  0     4318    1.116009  1     4319    1.705473 -1     4320    2.676980  0     4321              -0
 4322    -1.747908  1     4323    1.129825  1     4324    7.156454  0     4325    1.793375  1     4326    1.129875 -1
 4327     2.391606  1     4328    1.188111  1     4329    2.794695  0     4330    5.888031  1     4331    2.076291  0
 4332     4.589709  1     4333    9.100704-26     4334               0     4335    2.000000  0     4336    3.000000  0
 4872     1.108180  1     4873               0     4874   -1.705472 -1     4875   -1.129875 -1     4876   -3.156732  0
 4877    -6.964379  0     4878    1.116009  1     4879    1.705473 -1     4880    2.676979  0     4881               0
 4882    -1.747908  1     4883    1.129825  1     4884    7.156454  0     4885    1.793375  1     4886    1.129875 -1
 4887     2.391606  1     4888    1.188111  1     4889    2.794698  0     4890    5.888031  1     4891    2.076290  0
 4892     4.589709  1     4893               0     4894               0     4895              -0     4896   -3.725290 -9

                                           SHAPE COEFFICIENTS DO NOT CHECK
THE FOLLOWING INDICATORS ARE ON       DIVIDE CHECK
INDEX A HAS  7907 OR   285      INDEX B HAS      0 OR      0      INDEX C HAS  8034
 SENSE LIGHTS ON    NONE       SENSE SWITCHES ON    NONE
 4312     1.116955  1     4313               0     4314   -1.705472 -1     4315   -1.129875 -1     4316   -2.954733  0
 4317    -7.022513  0     4318    1.122759  1     4319    1.705473 -1     4320    2.521595  0     4321              -0
 4322    -1.761534  1     4323    1.136575  1     4324    7.201172  0     4325    1.807002  1     4326    1.129875 -1
 4327     2.430354  1     4328    1.197138  1     4329    3.108378  0     4330    5.962126  1     4331    1.942466  0
 4332     4.621155  1     4333    1.968472-25     4334               0     4335    2.000000  0     4336    3.000000  0
 4872     1.116955  1     4873               0     4874   -1.705472 -1     4875   -1.129875 -1     4876   -2.954731  0
 4877    -7.022513  0     4878    1.122759  1     4879    1.705473 -1     4880    2.521593  0     4881               0
 4882    -1.761534  1     4883    1.136575  1     4884    7.201173  0     4885    1.807002  1     4886    1.129875 -1
 4887     2.430354  1     4888    1.197138  1     4889    3.108381  0     4890    5.962126  1     4891    1.942464  0
 4892     4.621155  1     4893               0     4894               0     4895              -0     4896   -2.793968 -9
```

```
                                        PIPING FLEXIBIL    ANALYSIS - L03812
    TURBINE INLET  --  GRAVITY LOAD  --  CASE 5
                                    FREE ENDS - COORDINATES AND EXPANSION VALUES
    END            X            Y            Z                  EIDX                EIDY                EIDZ

    1          -1.98         0.66         2.30                 0.00                0.00                0.00

                                          SHAPE COEFFICIENTS DO NOT CHECK
THE FOLLOWING INDICATORS ARE ON       DIVIDE CHECK
INDEX A HAS  9165 OR    27      INDEX B HAS      0 OR     0      INDEX C HAS  7690
 SENSE LIGHTS ON   NONE      SENSE SWITCHES ON    NONE
 4312    1.625000 -1    4313              0    4314              0    4315              0    4316              0
 4317   -1.320312 -2    4318     2.112500 -1   4319              0    4320             -0    4321             -0
 4322           0       4323     1.625000 -1   4324    1.320312 -2    4325             -0    4326              0
 4327    3.439432 -3    4328             -0    4329             -0    4330    3.863642 -4    4331             -0
 4332    3.439432 -3    4333    -1.987098-31   4334              0    4335    2.000000  0    4336    3.000000  0
 4872    1.625000 -1    4873              0    4874              0    4875             -0    4876              0
 4877   -1.320313 -2    4878     2.112500 -1   4879              0    4880             -0    4881              0
 4882          -0       4883     1.625000 -1   4884    1.320313 -2    4885              0    4886             -0
 4887    3.439393 -3    4888              0    4889             -0    4890    3.863275 -4    4891    3.725290 -9
 4892    3.439412 -3    4893              0    4894              0    4895              0    4896             -0

                                          SHAPE COEFFICIENTS DO NOT CHECK
THE FOLLOWING INDICATORS ARE ON       DIVIDE CHECK
INDEX A HAS  8121 OR    71      INDEX B HAS      0 OR     0      INDEX C HAS  7690
 SENSE LIGHTS ON   NONE      SENSE SWITCHES ON    NONE
 4312    1.969308  0    4313              0    4314              0    4315              0    4316   -4.391066 -1
 4317   -9.273566 -1    4318     1.750163  0   4319    1.705473 -1    4320    5.034202 -1    4321             -0
 4322           0       4323     1.776413  0   4324    8.482375 -1    4325             -0    4326              0
 4327    6.777004 -1    4328             -0    4329              0    4330    1.964801 -1    4331    2.758631 -1
 4332    5.163125 -1    4333     0.471736 -7   4334              0    4335    2.000000  0    4336    3.000000  0
 4872    1.969308  0    4873              0    4874              0    4875             -0    4876   -4.391065 -1
 4877   -9.273566 -1    4878     1.750163  0   4879    1.705473 -1    4880    5.034202 -1    4881              0
 4882   -5.960464 -8    4883     1.776413  0   4884    8.482375 -1    4885    2.980232 -8    4886             -0
 4887    6.777000 -1    4888    -7.450581 -9   4889    1.788139 -7    4890    1.964798 -1    4891    2.758631 -1
 4892    5.163124 -1    4893              0    4894              0    4895              0    4896             -0

                                          SHAPE COEFFICIENTS DO NOT CHECK
THE FOLLOWING INDICATORS ARE ON       DIVIDE CHECK
INDEX A HAS  8058 OR   134      INDEX B HAS      0 OR     0      INDEX C HAS  7690
 SENSE LIGHTS ON   NONE      SENSE SWITCHES ON    NONE
 4312    4.561220  0    4313              0    4314   -1.705472 -1    4315   -1.129875 -1    4316   -3.936543  0
 4317   -2.644498  0    4318     4.366970  0   4319    1.705473 -1    4320    3.989525  0    4321             -0
 4322   -1.015906  0    4323     4.200325  0   4324    2.454079  0    4325    1.223053  0    4326    1.129875 -1
 4327    6.510087  0    4328     8.102728 -1   4329   -1.433960  0    4330    5.850893  0    4331    2.592914  0
 4332    2.466269  0    4333     1.125920-16   4334              0    4335    2.000000  0    4336    3.000000  0
 4872    4.561220  0    4873              0    4874   -1.705472 -1    4875   -1.129875 -1    4876   -3.936542  0
 4877   -2.644498  0    4878     4.366970  0   4879    1.705473 -1    4880    3.989525  0    4881              0
 4882   -1.015906  0    4883     4.200325  0   4884    2.454079  0    4885    1.223053  0    4886    1.129875 -1
 4887    6.510086  0    4888     8.102727 -1   4889   -1.433961  0    4890    5.850892  0    4891    2.592914  0
 4892    2.466268  0    4893              0    4894              0    4895             -0    4896   -2.793968 -9

                                          SHAPE COEFFICIENTS DO NOT CHECK
THE FOLLOWING INDICATORS ARE ON       DIVIDE CHECK
INDEX A HAS  7995 OR   197      INDEX B HAS      0 OR     0      INDEX C HAS  7690
 SENSE LIGHTS ON   NONE      SENSE SWITCHES ON    NONE
 4312    8.304133  0    4313              0    4314    5.215406 -8    4315    3.539026 -8    4316   -7.187995  0
 4317   -5.124177  0    4318     8.134778  0   4319    1.705473 -1    4320    7.676480  0    4321             -0
 4322   -9.871655  0    4323     8.120538  0   4324    5.051220  0    4325    1.027096  1    4326   -3.539026 -8
```

```
         TURBINE INLET  --  GRAVITY LOAD  --  CASE 5

                                         INPUT

    PLANE       ANGLE      LENGTH     O.D.      THICKNESS      TEMP      PHI       ROTATION
  ANCHOR NO.   1         PHI X       PHI Y      PHI Z       DELTA X      DELTA Y      DELTA Z
                         0.000       0.000      0.000       0.000        0.000        0.000
      1          0             0.16       1.8        0.095           0
 RESTRAINT  NO. 2        DIR.      KNOWN DEFLECTION   OR  KNOWN FORCE        CONSTANT FORCE (1=YES, 0=NO)
                          2             0.0000                -1.28                  1
      1         90             0.50       1.8        0.095           0        90           1
      1        270             0.25       1.8        0.095           0
 RESTRAINT  NO. 3        DIR.      KNOWN DEFLECTION   OR  KNOWN FORCE        CONSTANT FORCE (1=YES, 0=NO)
                          2             0.0000                -2.90                  1
      1        270             0.25       1.8        0.095           0
      2        180             0.50       1.8        0.095           0        90           0
      2        270             0.81       1.8        0.095           0
 RESTRAINT  NO. 4        DIR.      KNOWN DEFLECTION   OR  KNOWN FORCE        CONSTANT FORCE (1=YES, 0=NO)
                          2             0.0000                -5.07                  1
      2        270             0.81       1.8        0.095           0
      2        270             0.50       1.8        0.095           0        90           0
      2          0             1.40       1.8        0.095           0
 RESTRAINT  NO. 5        DIR.      KNOWN DEFLECTION   OR  KNOWN FORCE        CONSTANT FORCE (1=YES, 0=NO)
                          2             0.0000                -7.34                  1
      2          0             1.40       1.8        0.095           0
      2          0             0.50       1.8        0.095           0        90           0
      2         90             0.07       1.8        0.095           0
 RESTRAINT  NO. 6        DIR.      KNOWN DEFLECTION   OR  KNOWN FORCE        CONSTANT FORCE (1=YES, 0=NO)
                          2             0.0000                -2.19                  1
      2         90             0.07       1.8        0.095           0
  ANCHOR NO.   7         PHI X       PHI Y      PHI Z       DELTA X      DELTA Y      DELTA Z
                         0.000       0.000      0.000       0.000        0.000        0.000

         MODULUS OF ELASTICITY   19500000       MEAN EXPANSION COEFFICIENT  0.00001100
```

AEROJET GENERAL

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

QUADRILLE WORK SHEET

SUBJECT: TURBINE INLET COMBINED GRAVITY & PRESSURE STRESS, SL-1

BY

DATE

WORK ORDER

MAXIMUM PRINCIPAL STRESS $(S_1) = 0.5\left[\sigma_L + \sigma_P + \sqrt{4\tau^2 + (\sigma_L - \sigma_P)^2}\right]$

$$= 0.5\left[\sigma_P/2 + \sigma_B + \sigma_P + \sqrt{4\tau^2 + (\sigma_P/2 + \sigma_B - \sigma_P)^2}\right]$$

$$= 0.5\left[\frac{3\sigma_P}{2} + \sigma_B + \sqrt{4\tau^2 + (\sigma_B - \sigma_P/2)^2}\right]$$

WHERE σ_B MAY BE + OR −

$$\sigma_P = \frac{pD_o}{2t} = \frac{\overset{*}{285}(1.75)}{2(.085)}$$

$$t = t_{NOM} - CA = .095 - .010 = .085$$

$$I = \pi/64\,(D_o^4 - D_i^4) = \frac{\pi}{64}(1.75^4 - 1.58^4)$$

$$\sigma_B = \frac{M_B}{Z}$$

$$I = 0.153 \text{ IN}^4$$

$$\tau = \frac{M_T}{2Z}$$

$$Z = I/c = \frac{.153}{.875} = .175$$

<u>AT POINT 0 (I)</u>

$$M_B = \sqrt{M_x^2 + M_z^2} = \sqrt{25.6^2 + 14.7^2} = 29.4 \text{ FT-LBS} = 353 \text{ IN-LBS}$$

(REF. P. 9)

$$M_T \approx 0$$

$$\sigma_B = M_B/Z = \frac{353}{0.175} = 2010 \text{ PSI}$$

$$S_1 = 0.5\left[\frac{3}{2}(3030) \pm 2010 + \sqrt{0 + \left(-\frac{3030}{2} \pm 2010\right)^2}\right]$$

$$= 0.5\left[6560 + \sqrt{(-1515 + 2010)^2}\right] = 3520 \text{ PSI}$$

$$\text{OR} = 0.5\left[\frac{3}{2}(3030) - 2010 + \sqrt{(-1515 - 2010)^2}\right] = 3035 \text{ PSI}$$

* DESIGN PRESSURE FOR SL-1 GROUND TEST

AT POINT 13 (II)

$M_T = M_X = 28.2$ FT-LBS $= 339$ IN-LBS (REF. P. 9)

$M_y \approx 0$

$M_B = M_Z = 16.3$ FT-LBS $= 196$ IN-LBS

$\tau = M_T/2Z = \frac{339}{2(.175)} = 970$ PSI

$\sigma_B = M_B/Z' = \frac{196}{.175} = 1120$ PSI

$$\sigma_1 = 0.5\left[\frac{3(3030)}{2} \pm 1120 + \sqrt{4(970)^2 + (-1515 \pm 1120)^2}\right]$$

$$= 0.5\left[5640 + \sqrt{4(970)^2 + (-395)^2}\right]$$

$$= 0.5\left[5640 + 10^3\sqrt{4(.970)^2 + (.395)^2}\right] = 3810 \text{ PSI}$$

$$\text{OR} = 0.5\left[\frac{3(3030)}{2} - 1120 + \sqrt{4(970)^2 (-1515 - 1120)^2}\right]$$

$$= 3350 \text{ PSI}$$

MAXIMUM PRINCIPAL STRESS = 3810 PSI AT POINT 13 (II)

MARGIN OF SAFETY $= \frac{4000}{3810} - 1 = +.05$

NOTE: TURBINE INLET FLANGE HAS A WALL THICKNESS = .095"
DEAD LOAD STRESSES HAVE BEEN CALCULATED
BASED ON THIS THICKNESS

01-071-002

QUADRILLE WORK SHEET

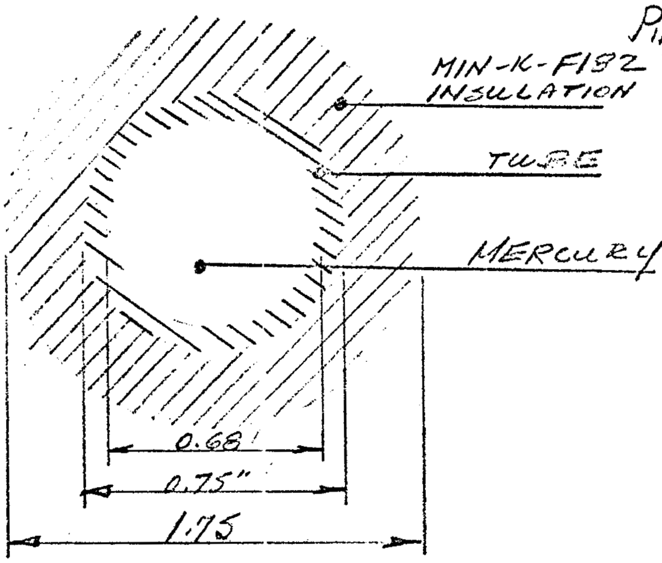
AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

PAGE 16 OF ______ PAGES

DATE ______

WORK ORDER ______

SUBJECT Hg BOILER INLET, SL-1 (I)
PIPING FLEX CALCULATIONS
~~(GRAVITY LOAD.)~~ BY ______



$\rho_{INSULATION} = \frac{16\ LB/FT^3}{1728} = .00925\ LB/IN^3$

$W_i = .785(1.75^2 - 0.75^2)(12)(.00925)$

$\underline{W_i = .218\ LBS/FT.}$

$W_p = .785(0.75^2 - 0.68^2)(12)(.283)$

$\underline{W_p = .262\ LB/FT}$

$\rho_{HG} = \frac{800\ LB}{FT^3} \times \frac{1}{1728} = .467 \frac{LB}{IN^3}$

$W_{HG} = .785(0.68)^2(12)(.467) =$

$\underline{W_{HG} = 2.02\ LB/FT}$

$W_{TOT} = .218 + .262 + 2.02 = \underline{\underline{2.50\ LB/FT}} =$ $\left\{\text{0.75" OD HG INLET}\right)$

QUADRILLE WORK SHEET

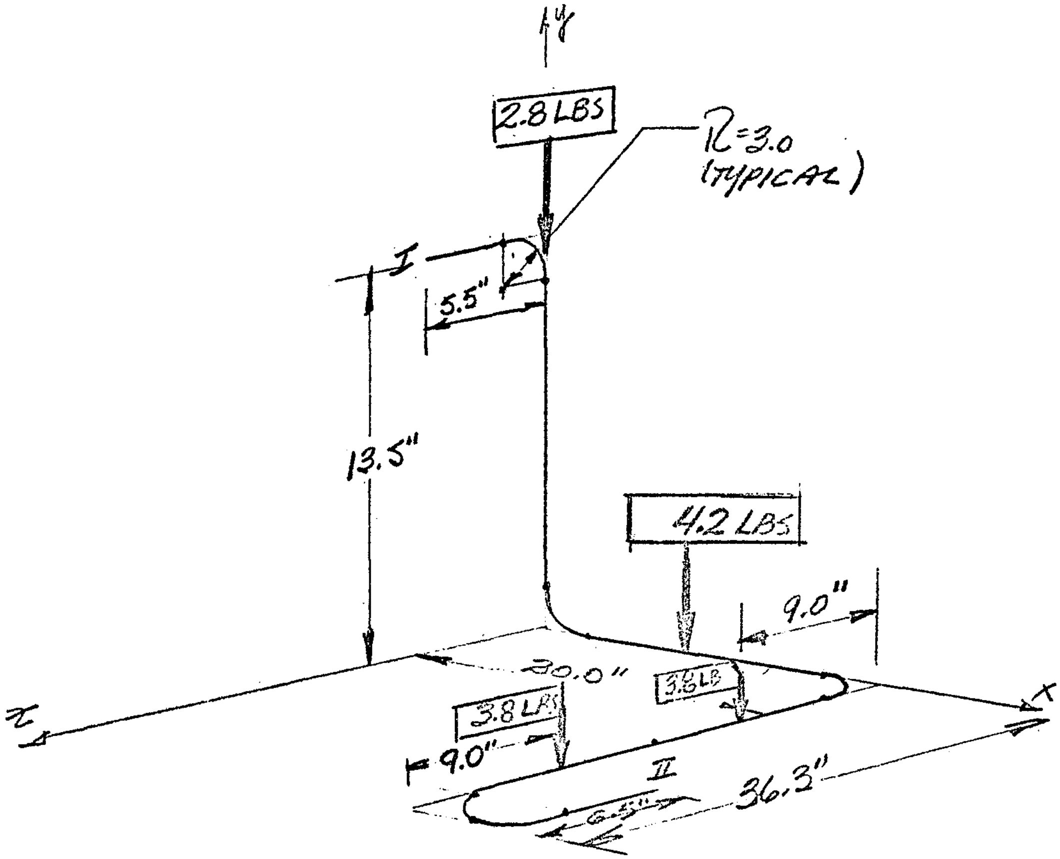
AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

SUBJECT: HG BOILER INLET, SL-1 (I) PIPING FLEXIBILITY CALC. (GRAVITY LOADS)

BY

DATE

WORK ORDER



DESIGN DATA

FIXITY AT BOTH ENDS

Do =0.750"

WALL THICKNESS = 0.035"

ALL BENDS ARE 90° BENDS.

NO WIND LOADS

A E T R O N
COVINA PLANT COVINA, CALIFORNIA
A DIVISION OF AEROJET-GENERAL CORPORATION

INPUT HG BOILER INLET GRAVITY LOADS

WIND IN X DIRECTION = -0. LBS/FT WIND IN Z DIRECTION = -0. LBS/FT

NO. OF BRANCHES = 1 NO. OF STOPS = -0 NO. OF CONCENTRATED WEIGHTS = 3

BRANCHES

BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.
1	1	14						

CONCENTRATED WEIGHTS IN LBS

POINT	WEIGHT	POINT	WEIGHT	POINT	WEIGHT
3	-2.800	6	-4.200	9	-3.800

ALLOWANCES AT ANCHORS

ANCHOR	DEFLECTIONS-INCHES DX	DY	DZ	ROTATIONS-DEGREES PHIX	PHIY	PHIZ
1	-0.	-0.	-0.	-0.	-0.	-0.
2	-0.	-0.	-0.	-0.	-0.	-0.

MEMBERS

MEM	NPL	ALPHA	RADIUS LENGTH	OD	TH	WT	POIS	EH	EE	TEMP	PHI	NQD	PRES
1	1	270.00	0.21	0.75	0.035	-0.	0.300	0.3000E 08	-0.	-0.	-0.	-0	-0.
2	1	0.	-0.25	0.75	0.035	-0.	0.300	0.3000E 08	-0.	-0.	90.00	1	-0.
3	1	180.00	0.63	0.75	0.035	-0.	0.300	0.3000E 08	-0.	-0.	-0.	-0	-0.
4	3	270.00	0.25	0.75	0.035	-0.	0.300	0.3000E 08	-0.	-0.	90.00	4	-0.
5	3	0.	0.58	0.75	0.035	-0.	0.300	0.3000E 08	-0.	-0.	-0.	-0	-0.
6	3	0.	0.58	0.75	0.035	-0.	0.300	0.3000E 08	-0.	-0.	-0.	-0	-0.
7	2	180.00	-0.25	0.75	0.035	-0.	0.300	0.3000E 08	-0.	-0.	90.00	3	-0.
8	2	0.	0.50	0.75	0.035	-0.	0.300	0.3000E 08	-0.	-0.	-0.	-0	-0.
9	2	0.	1.33	0.75	0.035	-0.	0.300	0.3000E 08	-0.	-0.	-0.	-0	-0.
10	2	0.	0.50	0.75	0.035	-0.	0.300	0.3000E 08	-0.	-0.	-0.	-0	-0.
11	2	0.	0.25	0.75	0.035	-0.	0.300	0.3000E 08	-0.	-0.	90.00	1	-0.
12	2	90.00	0.25	0.75	0.035	-0.	0.300	0.3000E 08	-0.	-0.	90.00	2	-0.
13	2	180.00	0.29	0.75	0.035	-0.	0.300	0.3000E 08	-0.	-0.	-0.	-0	-0.

MATRIX HAS BEEN MODIFIED -- CALL CHAIN 2

STRESS INTENSIFICATION FACTORS

SIF 1 = 1.0000	SIF 2 = 1.0000	SIF 3 = 1.0000	SIF 4 = 1.0000
SIF 5 = 1.0000	SIF 6 = 1.0000	SIF 7 = 1.0000	SIF 8 = 1.0000
SIF 9 = 1.0000	SIF 10 = 1.0000	SIF 11 = 1.0000	SIF 12 = 1.0000
SIF 13 = 1.0000	SIF		

ANCHOR	PCINT	THERMAL EXPANSIONS IN INCHES -		
2	14	DX = 0.	DY = 0.	DZ = 0.

A E T R O N
COVINA PLANT COVINA, CALIFORNIA
A DIVISION OF AEROJET-GENERAL CORPORATION

OUTPUT HG BOILER GRAVITY LOADS

THE MAXIMUM STRESS IS 5177.9226 PSI AT POINT 1 EXCLUDING STRESSES AT JUNCTIONS

REACTIONS OF ANCHORS ON PIPE

ANCHOR	POINT	MX (FT-LBS)	MY (FT-LBS)	MZ (FT-LBS)	FX (LBS)	FY (LBS)	FZ (LBS)
1	1	4.660	-0.144	3.444	-0.493	8.352	-0.085
2	14	2.012	-0.574	0.533	0.493	2.448	0.085

OUTPUT HG BOILER GRAVITY LOADS

	CO-CRDINATES IN FEET			PSI	ROTATION-DEGREES			DEFLECTION-INCHES		
POINT	X	Y	Z	STRESS	PHI X	PHI Y	PHI Z	DELT X	DELT Y	DELT Z
1	0.	0.	0.	5177.92	-0.	-0.	-0.	-0.	-0.	-0.
2	0.	0.	-0.21	4041.05	-0.0431	0.0022	-0.0508	-0.0000	-0.0011	0.
3	0.	-0.25	-0.46	3285.03	-0.1080	0.0278	-0.1725	-0.0071	-0.0050	0.0048
4	0.	-0.88	-0.46	3543.36	-0.1349	0.0442	-0.2995	-0.0378	-0.0050	0.0208
5	0.25	-1.13	-0.46	2448.78	-0.1591	0.0541	-0.4408	-0.0564	-0.0257	0.0257
6	0.83	-1.13	-0.46	953.77	-0.1897	0.0674	-0.4724	-0.0564	-0.0827	0.0183
7	1.42	-1.13	-0.46	1494.84	-0.2202	0.0822	-0.4398	-0.0564	-0.1386	0.0092
8	1.67	-1.13	-0.21	1873.41	-0.2572	0.1010	-0.3804	-0.0515	-0.1478	0.0045
9	1.67	-1.13	0.29	2220.87	-0.2958	0.1082	-0.3181	-0.0405	-0.1190	0.0045
10	1.67	-1.13	1.62	2115.67	-0.3049	0.0947	-0.1522	-0.0111	-0.0298	0.0045
11	1.67	-1.13	2.12	2976.15	-0.2472	0.0773	-0.0899	-0.0020	-0.0005	0.0045
12	1.92	-1.13	2.37	3245.65	-0.1473	0.0433	-0.0510	0.0014	0.0070	0.0016
13	2.17	-1.13	2.12	2563.30	-0.0378	0.0103	-0.0110	0.0003	0.0011	-0.0000
14	2.17	-1.13	1.83	1928.55	0.0000	-0.0000	0.0000	0.0000	-0.0000	0.0000

SUBJECT Hg BOILER INLET COMBINED GRAVITY & PRESSURE STRESS, SL-1 BY ______

$$\text{MAXIMUM PRINCIPAL STRESS} = 0.5\left[\frac{3\sigma_P}{2} + \sigma_B + \sqrt{4\tau^2 + \left(\sigma_B - \frac{\sigma_P}{2}\right)^2}\right]$$

WHERE σ_B CAN BE + OR −.

(REF. P. 14)

$\sigma_P = 6600$ PSI (REF. P.7)

$\sigma_B = M_B / Z$

$\tau = M_T / 2Z$

$I = \frac{\pi}{64}(D_o^4 - D_i^4) = \frac{\pi}{64}(.75^4 - .68^4)$

$= \frac{\pi}{64}(\overbrace{.315 - .213}^{.102}) = .0050\ IN^4$

$Z = I/C = \frac{.005}{.375} = .0133\ IN^3$

AT POINT 1 (I)

$M_B = M_X = 4.66$ FT-LBS $\equiv 56$ IN-LBS
$M_T = M_Z = 3.444$ FT-LBS $\equiv 41.3$ IN-LBS
(REF. P. 21)

$\sigma_B = M_B / Z = 56 / .0133 = 4220$ PSI

$\tau = M_T / 2(Z) = \frac{41.3}{2(.0133)} = 1560$ PSI

$$\text{MAXIMUM PRINCIPAL STRESS} = 0.5\left[\frac{3(6600)}{2} + 4220 + \sqrt{4(1560)^2 + \left(-\frac{6600}{2} + 4220\right)^2}\right]$$

$$= 0.5\left[9900 + 4220 + 10^3\sqrt{4(1.560)^2 + (.920)^2}\right] =$$

$= 0.5\left[14120 + 3250\right] =$ <u>8680 PSI = MAXIMUM PRINCIPAL STRESS</u>

$M.S. = \frac{14500}{8680} - 1 = +0.67$

NOTE: CORROSION ALLOWANCE NEGLECTED IN THIS CALCULATION

QUADRILLE WORK SHEET

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

PAGE 24 OF ______ PAGES
DATE ______
WORK ORDER ______

SUBJECT HG BOILER INLET COMBINED GRAVITY & PRESSURE STRESS BY ______

CHECK COMBINED STRESS AT THE "TEE" (POINT II) TAKING INTO ACCOUNT THE STRESS INTENSIFICATION AS APPLIED TO THE GRAVITY LOAD BENDING MOMENTS

$i = 4.26$ (REF P.32)

$Z = .0133 \text{ IN}^3$ (REF P.23)

$\left.\begin{array}{l} M_X = 2.012 \text{ FT-LBS} \\ M_Y = 0.574 \text{ FT-LBS} \\ M_Z = 0.533 \text{ FT-LBS} \end{array}\right\}$ (REF P. 21)

$M_T = M_Z = 0.533$ FT-LBS

$M_B = \sqrt{M_X^2 + M_Y^2} = \sqrt{2.012^2 + .574^2} = \sqrt{4.05 + .33} = \sqrt{4.38}$

$= 2.09$ FT-LBS

$\tau = \dfrac{M_T}{2Z} = \dfrac{0.533(12)}{2(.0133)} = 241$ PSI

$\sigma_B = \dfrac{i\,M_B}{Z} = \dfrac{4.26\,(2.09 \times 12)}{.0133} = 8040$ PSI

$\sigma_1 = 0.5\left[1.5\,(6600) + 8040 + \sqrt{4(241)^2 + \left(-\frac{6600}{2} + 8040\right)^2}\,\right]$

$= 0.5\left[\,17940 + \sqrt{232000 + 22500000}\,\right] = 0.5\left[17940 + 4770\right]$

$= 0.5\left[22710\right] = 11350$ PSI = MAXIMUM PRINCIPAL STRESS

$M.S. = \dfrac{14500}{11350} - 1 = 0.28$

SUMMARY –
PIPING THERMAL EXPANSION
STRESS MARGINS OF SAFETY

SUBJECT SL-1 BY ____

PIPE LINE DESIGNATION	S_{ALL} (PSI)*	S_{EMAX} (PSI)*	MARGIN OF SAFETY
BOILER HG INLET	22300	20800	+0.07
TURBINE SIMULATOR HG INLET	24400	5967	+3.08
CONDENSER HG OUTLET	22300	18450	+0.20
MERCURY PUMP HG INLET	22300	8142	+1.74
MERCURY PUMP HG OUTLET	22300	4723	+3.72
TURBINE HG INLET	24400	4816	+4.07
FLOW CONTROL VALVE HG INLET	22300	3037	+6.35

NOTES

1.* REF. PGS 26 TO 74.

2. NAK INLETS & OUTLETS TO THE BOILER & CONDENSER ARE NOT INDICATED ON THIS SHEET, AS ANY THERMAL EXPANSION IN THESE LINES IS ABSORBED BY EXPANSION JOINTS.

3. EQUIVILENT STRESSES, AS LISTED ABOVE, WERE COMPUTED BASED ON THE HOT MODULUS OF ELASTICITY RATHER THAN THE COLD MODULUS, WHICH THE PIPING CODE RECOMMENDS. THIS WAS DONE, SINCE THE OPERATING LOAD ON THE COMPONENT CONNECTION IS USUALLY CRITICAL RATHER THAN THE PIPING THERMAL EXPANSION STRESS. BY INSPECTION, HOWEVER, IT CAN BE SEEN THAT ALL MARGINS OF SAFETY WOULD STILL BE POSITIVE IF THE COLD MODULUS WAS USED.

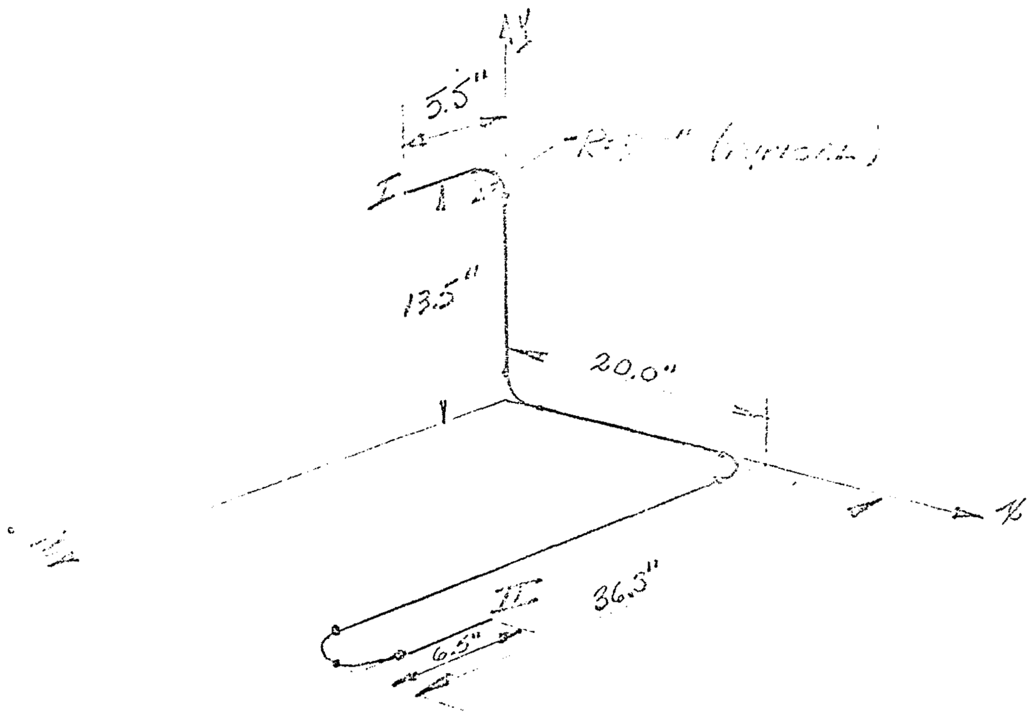
QUADRILLE WORK SHEET

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

DATE ____

WORK ORDER ____

SUBJECT ____ BY ____



FIXITY AT I & II

$D_o = 0.75''$

WALL THICKNESS = 0.035"

TEMP = 515°F, ΔT = 445°F

$E = 28.5 \times 10^6$ PSI

$\alpha = 6.53 \times 10^{-6}$ IN/IN-°F

ALL BENDS ARE 90° BENDS

END MOVEMENTS

POINT I

$\delta_x = 0$

$\delta_y = -.648''$

$\delta_z = -.250''$

$\theta_x = \theta_y = \theta_z = 0$

POINT II

$\delta_x = 0$

$\delta_y = 0$

$\delta_z = .021''$

$\theta_x = \theta_y = \theta_z = 0$

$S_{ALL} = 1.25 S_c + 0.25 S_H = 1.25(15000) + .25(1\ldots$

INPUT FG BOILER INLET, SLY(I)

WIND IN X DIRECTION = -0. LBS/FT WIND IN Z DIRECTION = -0. LBS/FT

NO. OF BRANCHES = 1 NO. OF STOPS = -0 NO. OF CONCENTRATED WEIGHTS = -0

BRANCHES

BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.
1	1	11						

ALLOWANCES AT ANCHORS

ANCHOR	DEFLECTIONS-INCHES DX	DY	DZ	ROTATIONS-DEGREES PHIX	PHIY	PHIZ
1	-0.	-0.6480	-0.2500	-0.	-0.	-0.
2	-0.	-0.	-0.2100	-0.	-0.	-0.

MEMBERS

MEM	NPL	ALPHA	RADIUS LENGTH	OD	TH	WT	POIS	EH	EE	TEMP	PHI	NQD	PRES
1	1	270.00	0.21	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.
2	1	0.	-0.33	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	90.00	1	-0.
3	1	180.00	0.63	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.
4	3	270.00	0.33	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	90.00	4	-0.
5	3	0.	1.16	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.
6	2	180.00	-0.33	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	90.00	3	-0.
7	2	0.	2.52	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.
8	2	0.	0.33	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	90.00	1	-0.
9	2	90.00	0.33	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	90.00	2	-0.
10	2	270.00	0.29	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.

MATRIX HAS BEEN MODIFIED -- CALL CHAIN 2

STRESS INTENSIFICATION FACTORS

SIF 1 = 1.0000 SIF 2 = 1.0000 SIF 3 = 1.0000 SIF 4 = 1.0000
SIF 5 = 1.0000 SIF 6 = 1.0000 SIF 7 = 1.0000 SIF 8 = 1.0000
SIF 9 = 1.0000 SIF 10 = 1.0000 SIF

ANCHOR	POINT	THERMAL EXPANSIONS IN INCHES -		
2	11	DX = 0.076366	DY = -0.044808	DZ = 0.080620

PAGE 39

A E T R O N

COVINA PLANT COVINA, CALIFORNIA

A DIVISION OF AEROJET-GENERAL CORPORATION

OUTPUT - HG BOILER INLET, SLY(I) PAGE 1

THE MAXIMUM STRESS IS 6383.0403 PSI AT POINT 9 EXCLUDING STRESSES AT JUNCTIONS

REACTIONS OF ANCHORS ON PIPE

		FT-LBS			LBS		
ANCHOR	POINT	MX	MY	MZ	FX	FY	FZ
1	1	-1.776	-2.795	-1.658	2.464	-3.367	3.340
2	11	5.269	1.178	-2.550	-2.464	3.367	-3.340

A E T R O N

COVINA PLANT COVINA, CALIFORNIA

A DIVISION OF AEROJET-GENERAL CORPORATION

OUTPUT HG BOILER INLET, SLY(I)

POINT	CO-ORDINATES IN FEET X	Y	Z	PSI STRESS	ROTATION-DEGREES PHI X	PHI Y	PHI Z	DEFLECTION-INCHES DELT X	DELT Y	DELT Z
1	0.	0.	0.	3307.91	-0.	-0.	-0.	-0.	-0.6480	-0.2500
2	0.	0.	-0.21	2696.71	0.0170	0.0303	0.0258	-0.0007	-0.6476	-0.2573
3	0.	-0.33	-0.54	2762.14	0.0155	0.1013	0.1051	-0.0000	-0.6573	-0.2706
4	0.	-0.96	-0.54	4781.98	-0.0628	0.1698	0.2216	0.0207	-0.6790	-0.2683
5	0.33	-1.29	-0.54	5104.87	-0.2259	0.2050	0.4115	0.0524	-0.6668	-0.2736
6	1.49	-1.29	-0.54	4979.51	-0.6010	0.1003	0.5289	0.0928	-0.5471	-0.3160
7	1.82	-1.29	-0.21	4595.25	-0.7643	-0.0799	0.5008	0.1034	-0.4622	-0.3070
8	1.82	-1.29	2.31	5306.72	-0.6156	-0.1800	0.2554	-0.0050	-0.0437	-0.2192
9	2.15	-1.29	2.64	6383.04	-0.3593	-0.0635	0.1681	-0.0029	0.0066	-0.2005
10	2.48	-1.29	2.31	5666.91	-0.1142	-0.0116	0.0506	0.0101	0.0014	-0.2095
11	2.19	-1.29	2.31	5333.95	0.0000	-0.0000	-0.0000	0.0000	-0.0000	-0.2100

SUBJECT BOILER HG INLET, SL-1 PIPING FLEXIBILITY CALC. (THERMAL)

BY ____

CHECK STRESS AT "II" TAKING INTO ACCOUNT INTENSIFICATION DUE TO A "TEE" IN THE LINE. "TEE" IS FABRICATED WITH BOTH HEADER AND BRANCH 0.75 INCH O.D., WALL THICKNESS = 0.035 INCHES.

(REF. PIPING CODE, ASA. B31.1-1955, FIG 2)

$$h = t/r_m = \frac{.035}{.357} = .098$$

$$i = \frac{0.9}{h^{2/3}} = \frac{0.9}{(.098)^{.67}} = \frac{0.9}{.211} = 4.26$$

$$M_T = M_Z = 2.55 \text{ FT-LBS}$$

$$M_B = \sqrt{M_x^2 + M_y^2} = \sqrt{5.269^2 + 1.178^2} = \sqrt{27.80 + 1.39} = \sqrt{29.19}$$
$$= 5.4 \text{ FT-LBS}$$

$Z = .0133 \text{ IN}^3$ (REF. P. 24)

$$\tau = \frac{M_T}{2Z} = \frac{2.55 \times 12}{2(.0133)} = 1150 \text{ PSI}$$

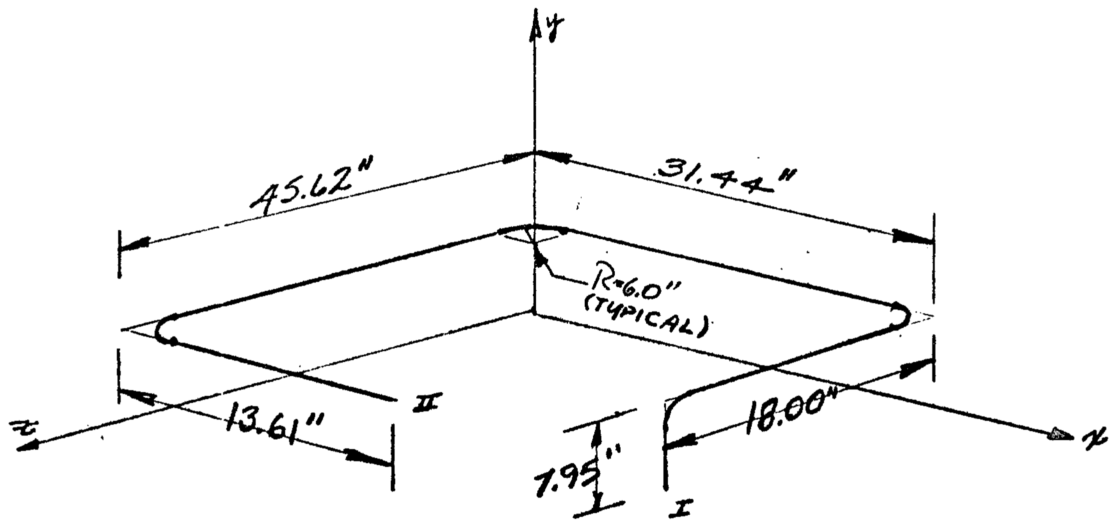
$$\sigma_B = \frac{iM_B}{Z} = \frac{4.26(5.4 \times 12)}{.0133} = 20700 \text{ PSI}$$

$$S_E = \sqrt{\sigma_B^2 + 4\tau^2} = \sqrt{20700^2 + 4 \times 1150^2} = 10^4\sqrt{2.07^2 + 4 \times .115^2}$$

$$= 10^4\sqrt{4.290 + .053} = 10^4\sqrt{4.343} = 20800 \text{ PSI}$$

SUBJECT: TURBINE SIMULATOR (II) HG INLET PIPING FLEXIBILITY CALCULATIONS, SL-1 (THERMAL)

BY ___



FIXITY AT BOTH ENDS

$D_o = 1.75$ INCHES

WALL THICKNESS = 0.120"

TEMPERATURE = 1300°F

$E = 19.50 \times 10^6$ PSI

$\alpha = 11.0 \times 10^{-6}$ IN/IN-°F

END MOVEMENTS

POINT I

$\delta_x = 0.142"$
$\delta_y = 0.112"$
$\delta_z = 0$
$\theta_x = \theta_y = \theta_z = 0$

POINT II

$\delta_x = -0.06"$
$\delta_y = -0.26"$
$\delta_z = 0.09"$
$\theta_x = \theta_y = \theta_z = 0$

$S_{ALL} = 1.25\ S_C + 0.25\ S_H = 1.25(18750) + 0.25(4000)$

$S_{ALL} = 24{,}400$ PSI

INPUT TURBINE INLET -- THERMAL LOAD -- CASE 5 PAGE 1

WIND IN X DIRECTION = -0. LBS/FT WIND IN Z DIRECTION = -0. LBS/FT

NO. OF BRANCHES = 1 NO. OF STOPS = -0 NO. OF CONCENTRATED WEIGHTS = -0

BRANCHES

BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.
1	1	14						

ALLOWANCES AT ANCHORS

ANCHOR	DEFLECTIONS-INCHES DX	DY	DZ	ROTATIONS-DEGREES PHIX	PHIY	PHIZ
1	1.4200000E-01	1.6200000E-01	-0.	-0.	-0.	-0.
2	-5.9999999E-02	-2.6000000E-01	8.9999999E-02	-6.9999999E-03	-0.	-0.

MEMBERS

MEM	NPL	ALPHA	RADIUS LENGTH	OD	TH	WT	POIS	EH	EE	TEMP	PHI	NOD	EC
1	1	0.	0.16	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
2	1	90.00	-0.50	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	90.00	2	-0.
3	1	270.00	0.25	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
4	1	270.00	0.25	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
5	2	180.00	0.50	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	90.00	3	-0.
6	2	270.00	0.81	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
7	2	270.00	0.81	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
8	2	270.00	0.50	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	90.00	4	-0.
9	2	0.	1.40	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
10	2	0.	1.40	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
11	2	0.	0.50	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	90.00	1	-0.
12	2	90.00	0.07	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
13	2	90.00	0.57	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.

STRESS INTENSIFICATION FACTORS

```
SIF  1 = 0.09999999E 01   SIF  2 = 0.09999999E 01   SIF  3 = 0.09999999E 01   SIF  4 = 0.09999999E 01
SIF  5 = 0.09999999E 01   SIF  6 = 0.09999999E 01   SIF  7 = 0.09999999E 01   SIF  8 = 0.09999999E 01
SIF  9 = 0.09999999E 01   SIF 10 = 0.09999999E 01   SIF 11 = 0.09999999E 01   SIF 12 = 0.09999999E 01
SIF 13 = 0.09999999E 01   SIF
```

INPUT TO MATRIX

```
C  1 = 0.11637741E 02     C  2 = 0.                 C  3 =-0.14753181E-00     C  4 =-0.15730579E 01
C  5 = 0.11642371E 03     C  6 =-0.12372325E 03     C  7 =-0.28077941E 01     C

C  1 = 0.                 C  2 = 0.11473717E 02     C  3 = 0.14753177E-00     C  4 =-0.11194856E 03
C  5 =-0.14753177E 01     C  6 = 0.96621253E 02     C  7 = 0.                 C

C  1 =-0.14753181E-00     C  2 = 0.14753177E-00     C  3 = 0.11720339E 02     C  4 = 0.12317073E 03
C  5 =-0.99872269E 02     C  6 = 0.30483756E 01     C  7 = 0.                 C

C  1 =-0.15730579E 01     C  2 =-0.11194856E 03     C  3 = 0.12317073E 03     C  4 = 0.24390129E 04
C  5 =-0.10469142E 04     C  6 =-0.91664847E 03     C  7 = 0.75141006E 02     C

C  1 = 0.11642371E 03     C  2 =-0.14753177E 01     C  3 =-0.99872269E 02     C  4 =-0.10469142E 04
C  5 = 0.20249079E 04     C  6 =-0.12524935E 04     C  7 =-0.10487485E 04     C

C  1 =-0.12372325E 03     C  2 = 0.96621253E 02     C  3 = 0.30483756E 01     C  4 =-0.91664847E 03
C  5 =-0.12524935E 04     C  6 = 0.21428271E 04     C  7 =-0.51349801E 03     C
```

N		N+1		N+2	
CALCULATED CONSTANT	ACTUAL CONSTANT	CALCULATED CONSTANT	ACTUAL CONSTANT	CALCULATED CONSTANT	ACTUAL CONSTANT
-0.28077392E 01	-0.28077941E 01	-0.61035156E-04	0.	-0.11444092E-04	0.
0.75141601E 02	0.75141006E 02	-0.10487480E 04	-0.10487485E 04	-0.51350000E 03	-0.51349801E 0

ANCHOR	POINT	THERMAL EXPANSIONS IN INCHES -		
2	14	DX =-0.24123452E-00	DY = 0.10756348E-00	DZ = 0.37375262E-00

SOLUTIONS TO MATRIX

R 1 =-0.22531488E 03   R 2 = 0.61718448E 03   R 3 =-0.47047782E 03   R 4 = 0.19970478E 02
R 5 =-0.30861560E 02   R 6 =-0.49904691E 02   R

A E T R O N

COVINA PLANT COVINA, CALIFORNIA

A DIVISION OF AEROJET-GENERAL CORPORATION

OUTPUT TURBINE ~~INLET~~ SIMULATOR INLET - MLA-1 -- THERMAL LOAD -- CASE 5

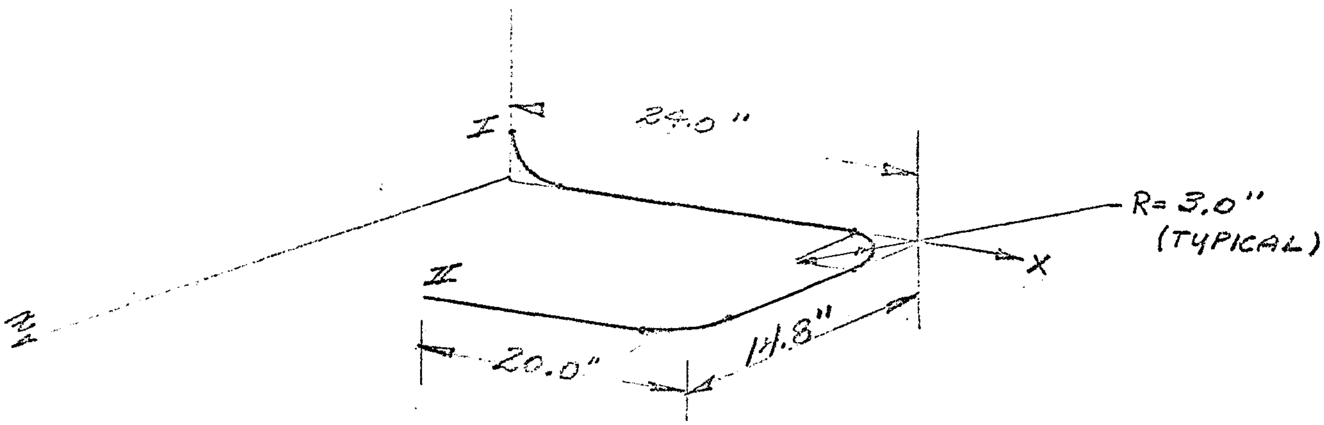
R'=1.21 DUE TO t=0.120" RATHER THAN .095" (ONLY END LOADS CORRECTED)

REACTIONS OF ANCHORS ON PIPE

		FT-LBS			LBS		
ANCHOR	POINT	MX	MY	MZ	FX	FY	FZ
1	1	~~34.884~~ 42.2	~~81.567~~ 98.7	~~-37.843~~ -45.8	~~-19.970~~ -24.2	~~30.862~~ 37.4	~~49.905~~ 60.4
2	14	~~-72.865~~ -88.0	~~-53.391~~ -64.7	~~5.219~~ 6.3	~~-19.970~~ 24.2	~~-30.862~~ -37.4	~~-49.905~~ -60.4

	CO-ORDINATES IN FEET			PSI	ROTATION-DEGREES			DEFLECTION-INCHES		
POINT	X	Y	Z	STRESS	PHI X	PHI Y	PHI Z	DELT X	DELT Y	DELT Z
1	0.	0.	0.	5967.09	-0.	-0.	-0.	0.1420	0.1620	-0.
2	0.	0.16	0.	5888.36	-0.0125	-0.0430	0.0160	0.1418	0.1884	-0.0003
3	0.	0.66	-0.50	5505.15	-0.0320	-0.2676	0.1342	0.1541	0.2654	-0.0851
4	0.	0.66	-0.75	5357.04	-0.0212	-0.3107	0.1755	0.1693	0.2639	-0.1257
5	0.	0.66	-1.00	5266.45	-0.0055	-0.3506	0.2169	0.1866	0.2631	-0.1663
6	-0.50	0.66	-1.50	3892.68	0.0971	-0.5215	0.3426	0.1500	0.2354	-0.2971
7	-1.31	0.66	-1.50	2954.44	0.2139	-0.5345	0.3893	0.0185	0.1724	-0.3880
8	-2.12	0.66	-1.50	4426.90	0.3306	-0.4659	0.3856	-0.1130	0.1058	-0.4743
9	-2.62	0.66	-1.00	4992.86	0.4410	-0.2200	0.3264	-0.2270	0.0254	-0.4333
10	-2.62	0.66	0.40	3264.44	0.4670	-0.0273	0.1912	-0.2608	-0.1118	-0.2059
11	-2.62	0.66	1.80	4085.19	0.3419	0.0676	0.0559	-0.2523	-0.2345	0.0215
12	-2.12	0.66	2.30	4787.55	0.1428	0.0594	0.0072	-0.1630	-0.2600	0.0947
13	-2.05	0.66	2.30	4828.29	0.1268	0.0555	0.0050	-0.1520	-0.2599	0.0939
14	-1.49	0.66	2.30	5598.06	-0.0070	-0.0000	-0.0000	-0.0600	-0.2600	0.0900

NOTE: END LOADS WERE CORRECTED BY MULTIPLYING "TYPED VALUE" BY R' TO CORRECT FOR CHANGED PIPE WALL THICKNESS.



FIXITY AT "I" & "II"

$D_o = 1.00''$

WALL THICKNESS = 0.035"

TEMP. = 505°F , $\Delta T = 435°F$

$E = 28.5 \times 10^6$ PSI

$\alpha = 6.53 \times 10^{-6}$ IN/IN - °F

ALL BENDS ARE 90° BENDS

END MOVEMENTS

POINT I

$\delta_x = -.020''$
$\delta_y = -.198''$
$\delta_z = 0$
$\theta_x = \theta_y = \theta_z = 0$

POINT II

$\delta_x = .021''$
$\delta_y = .027''$
$\delta_z = 0$
$\theta_x = \theta_y = \theta_z = 0$

$S_{ALL} = 1.25\, S_C + 0.25\, S_H = 1.25(15000) + 0.25(14500)$

$S_{ALL} = 22,300$ PSI

A E T R O N
COVINA PLANT COVINA, CALIFORNIA
A DIVISION OF AEROJET-GENERAL CORPORATION

INPUT CONDENSER HG OUTLET, SL-1(I) PAGE 1

WIND IN X DIRECTION = -0. LBS/FT WIND IN Z DIRECTION = -0. LBS/FT

NO. OF BRANCHES = 1 NO. OF STOPS = -0 NO. OF CONCENTRATED WEIGHTS = -0

BRANCHES

BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.
1	1	7						

ALLOWANCES AT ANCHORS

ANCHOR	DEFLECTIONS-INCHES DX	DY	DZ	ROTATIONS-DEGREES PHIX	PHIY	PHIZ
1	-0.0200	-0.1980	-0.	-0.	-0.	-0.
2	0.0210	0.0270	-0.	-0.	-0.	-0.

MEMBERS

MEM	NPL	ALPHA	RADIUS LENGTH	OD	TH	WT	POIS	EH	EE	TEMP	PHI	NQD	PRES
1	3	270.00	0.25	1.00	0.035	-0.	0.300	0.2850E 08	0.6530E-05	435.	90.00	4	-0.
2	2	90.00	1.50	1.00	0.035	-0.	0.300	0.2850E 08	0.6530E-05	435.	-0.	-0	-0.
3	2	180.00	-0.25	1.00	0.035	-0.	0.300	C.2850E 08	0.6530E-05	435.	90.00	3	-0.
4	2	0.	0.73	1.00	0.035	-0.	0.300	0.2850E 08	0.6530E-05	435.	-0.	-0	-0.
5	2	90.00	-0.25	1.00	0.035	-0.	0.300	0.2850E 08	0.6530E-05	435.	90.00	2	-0.
6	2	270.00	1.42	1.00	0.035	-0.	0.300	0.2850E 08	0.6530E-05	435.	-0.	-0	-0.

MATRIX HAS BEEN MODIFIED -- CALL CHAIN 2

STRESS INTENSIFICATION FACTORS

SIF 1 = 1.4830 SIF 2 = 1.0000 SIF 3 = 1.4830 SIF 4 = 1.0000
SIF 5 = 1.4830 SIF 6 = 1.0000 SIF

ANCHOR	POINT	THERMAL EXPANSIONS IN INCHES -		
2	7	DX = 0.011249	DY = -0.008522	DZ = 0.042029

PAGE 43

A E T R O N

COVINA PLANT COVINA, CALIFORNIA

A DIVISION OF AEROJET-GENERAL CORPORATION

OUTPUT CONDENSER HG OUTLET, SL-1(I)

THE MAXIMUM STRESS IS 8197.5349 PSI AT POINT 1 EXCLUDING STRESSES AT JUNCTIONS

REACTIONS OF ANCHORS ON PIPE

		FT-LBS			LBS		
ANCHOR	POINT	MX	MY	MZ	FX	FY	FZ
1	1	4.028	-4.551	-10.210	-1.555	-8.497	2.667
2	7	5.783	1.754	7.018	1.555	8.497	-2.667

A E T R O N

COVINA PLANT COVINA, CALIFORNIA

A DIVISION OF AEROJET-GENERAL CORPORATION

OUTPUT CONDENSER HG OUTLET, SL-1(I)

POINT	CO-ORDINATES IN FEET X	Y	Z	PSI STRESS	ROTATION-DEGREES PHI X	PHI Y	PHI Z	DEFLECTION-INCHES DELT X	DELT Y	DELT Z
1	0.	0.	0.	8197.53	-0.	-0.	-0.	-0.0200	-0.1980	-0.
2	0.25	-0.25	0.	6606.33	-0.0689	0.0648	0.2956	-0.0055	-0.1962	0.0000
3	1.75	-0.25	-0.00	4286.68	-0.2831	0.1310	0.3421	0.0457	-0.0841	-0.0345
4	2.00	-0.25	0.25	4028.66	-0.3235	0.1090	0.2312	0.0605	-0.0527	-0.0326
5	2.00	-0.25	0.98	4667.92	-0.3142	0.0792	0.0712	0.0752	-0.0023	-0.0076
6	1.75	-0.25	1.23	4815.51	-0.2498	0.0046	-0.0327	0.0694	0.0119	0.0025
7	0.33	-0.25	1.23	4491.69	-0.0000	-0.0000	0.0000	0.0210	0.0270	-0.0000

PAGE 45

CONDENSER HG OUTLET, SL-1

SUBJECT PIPING FLEXIBILITY CALC. BY A.L.

(THERMAL)

CHECK STRESS AT "II" TAKING INTO ACCOUNT INTENSIFICATION DUE TO A "TEE" IN THE LINE.

"TEE" IS FABRICATED WITH BOTH HEADER AND BRANCH 1 INCH O.D., WALL THICKNESS = 0.035 INCHES.

(REF. PIPING CODE, ASA B31.1-1955, FIG 2)

$h_1 = t/r_m = \frac{.035}{.482} = .0727$ $\quad r_m = 0.5 - .018 = .482$

$i = \frac{0.9}{h^{2/3}} = \frac{0.9}{(.0727)^{.67}} = \frac{0.9}{.172} = 5.23$

$M_T = M_X = 5.783$ FT-LBS

$M_B = \sqrt{M_Y^2 + M_Z^2} = \sqrt{1.754^2 + 7.018^2} = \sqrt{3.07 + 49.2} = \sqrt{52.27} = 7.22$ F

$\tau = \frac{M_T}{2Z} = \frac{5.783 \times 12}{2(.0248)} = 1400$ PSI

$\sigma_B = \frac{i M_B}{Z} = \frac{5.23(7.22 \times 12)}{.0248} = 18300$ PSI

$I = \frac{\pi}{64}(D_o^4 - D_i^4)$

$= \frac{\pi}{64}(1^4 - .93^4) = \frac{\pi}{64}(.253)$

$= .0124$ IN^4

$S_E = \sqrt{\sigma_B^2 + 4\tau^2} = \sqrt{(18300)^2 + 4(1400)^2}$

$= 10^4\sqrt{1.83^2 + 4 \times .14^2} = 10^4\sqrt{3.340 + .079}$

$= 10^4\sqrt{3.419} = 18450$ PSI

$Z = I/c = \frac{.0124}{.5} = .0248$ IN^3

01-071-002

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

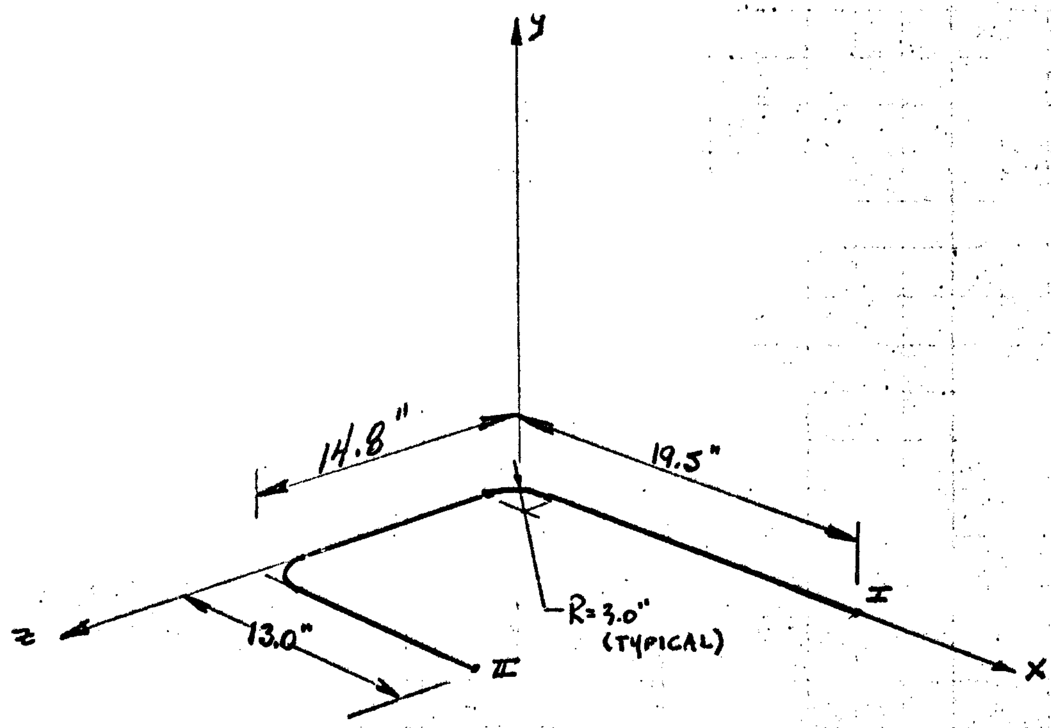
QUADRILLE WORK SHEET

DATE

SUBJECT: MERCURY PUMP Hg INLET (I), SL-1 PIPING FLEXIBILITY CALC. (THERMAL)

BY

WORK ORDER



FIXITY AT "I" & "II"

$D_o = 1.0''$

WALL THICKNESS = 0.035"

TEMP. = 505°F, $\Delta T = 435°F$

$E = 28.5 \times 10^6$ PSI

$\alpha = 6.53 \times 10^{-6}$ IN/IN-°F.

ALL BENDS ARE 90° BENDS

END MOVEMENTS

POINT I

$\delta x = .00$

$\delta y = .026''$

$\delta z = .035''$

$\theta x = \theta y = \theta z = 0$

POINT II

$\delta x = 0$

$\delta y = 0$

$\delta z = 0$

$\theta x = \theta y = \theta z = 0$

$S_{ALL} = 1.25\, S_C + 0.25\, S_H = 1.25(15000) + 0.25(14500)$

$S_{ALL} = 223$[illegible] PSI

A E T R O N

COVINA PLANT COVINA, CALIFORNIA

A DIVISION OF AEROJET-GENERAL CORPORATION

INPUT HG PUMP INLET (I), SL-1

WIND IN X DIRECTION = -0. LBS/FT WIND IN Z DIRECTION = -0. LBS/FT

NO. OF BRANCHES = 1 NO. OF STOPS = -0 NO. OF CONCENTRATED WEIGHTS = -0

BRANCHES

BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.
1	1	6						

ALLOWANCES AT ANCHORS

ANCHOR	DEFLECTIONS-INCHES DX	DY	DZ	ROTATIONS-DEGREES PHIX	PHIY	PHIZ
1	-0.	0.0260	0.0350	-0.	-0.	-0.
2	-0.	-0.	-0.	-0.	-0.	-0.

MEMBERS

MEM	NPL	ALPHA	RADIUS LENGTH	OD	TH	WT	POIS	EH	EE	TEMP	PHI	NOD	PRES
1	2	270.00	1.38	1.00	0.035	-0.	0.300	0.2850E 08	0.6530E-05	435.	-0.	-0	-0.
2	2	270.00	0.25	1.00	0.035	-0.	0.300	0.2850E 08	0.6530E-05	435.	90.00	4	-0.
3	2	0.	0.73	1.00	0.035	-0.	0.300	0.2850E 08	0.6530E-05	435.	-0.	-0	-0.
4	2	0.	0.25	1.00	0.035	-0.	0.300	0.2850E 08	0.6530E-05	435.	90.00	1	-0.
5	2	90.00	0.83	1.00	0.035	-0.	0.300	0.2850E 08	0.6530E-05	435.	-0.	-0	-0.

MATRIX HAS BEEN MODIFIED -- CALL CHAIN 2

STRESS INTENSIFICATION FACTORS

SIF 1 = 1.0000 SIF 2 = 1.4830 SIF 3 = 1.0000 SIF 4 = 1.4830
SIF 5 = 1.0000 SIF

ANCHOR	POINT	THERMAL EXPANSIONS IN INCHES -		
2	6	DX = -0.018475	DY = 0.	DZ = 0.042029

A E T R O N

COVINA PLANT COVINA, CALIFORNIA

A DIVISION OF AEROJET-GENERAL CORPORATION

OUTPUT HG PUMP INLET (I), SL-1

THE MAXIMUM STRESS IS 8142.2681 PSI AT POINT 1 EXCLUDING STRESSES AT JUNCTIONS

REACTIONS OF ANCHORS ON PIPE

		FT-LBS			LBS		
ANCHOR	POINT	MX	MY	MZ	FX	FY	FZ
1	1	-1.176	16.553	-2.536	-5.446	2.189	15.585
2	6	-1.523	-14.820	1.349	5.446	-2.189	-15.585

A E T R O N
COVINA PLANT COVINA, CALIFORNIA
A DIVISION OF AEROJET-GENERAL CORPORATION

OUTPUT HG PUMP INLET (I), SL-1

	CO-ORDINATES IN FEET			PSI	ROTATION-DEGREES			DEFLECTION-INCHES		
POINT	X	Y	Z	STRESS	PHI X	PHI Y	PHI Z	DELT X	DELT Y	DELT Z
1	0.	0.	0.	8142.27	-0.	-0.	-0.	-0.	0.0260	0.0350
2	-1.38	0.	0.	3570.05	0.0492	-0.1879	0.0332	-0.0468	0.0183	-0.0090
3	-1.63	0.	0.25	5372.93	0.0642	0.0329	0.0226	-0.0582	0.0143	-0.0066
4	-1.63	0.	0.98	2605.47	0.0612	0.1258	-0.0002	-0.0451	0.0043	0.0183
5	-1.38	0.	1.23	1552.21	0.0386	0.1624	-0.0085	-0.0284	0.0013	0.0181
6	-0.54	0.	1.23	7255.63	0.0000	-0.0000	-0.0000	-0.0000	0.0000	-0.0000

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

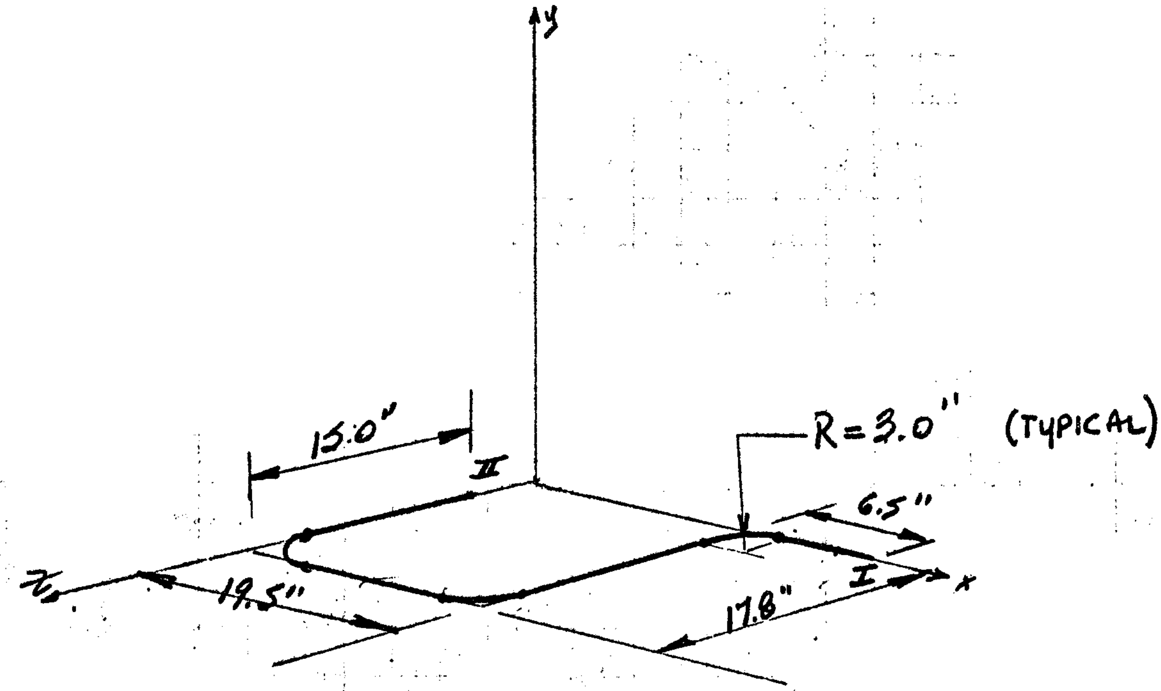
QUADRILLE WORK SHEET

DATE ____

SUBJECT: MERCURY PUMP HG OUTLET (I), SL-1 PIPING FLEXIBILITY CALCUL. (THERMAL)

BY ____

WORK ORDER ____



FIXITY AT "I" & "II"

$D_o = 0.75"$

WALL THICKNESS - 0.035"

TEMP. = 515°F, ΔT = 445°F

$E = 28.5 \times 10^6$ PSI

$\alpha = 6.53 \times 10^{-6}$ IN/IN-°F

ALL BENDS ARE 90 BENDS

END MOVEMENTS

POINT I

$\delta_x = -.013"$
$\delta_y = .032"$
$\delta_z = .022"$
$\theta_x = \theta_y = \theta_z = 0$

POINT II

$\delta_x = 0$
$\delta_y = 0$
$\delta_z = .018"$
$\theta_x = \theta_y = \theta_z = 0$

$S_{ALL.} = 1.25\, S_C + 0.25\, S_H = 1.25\,(15000) + 0.25\,(14500) =$

$S_{ALL.} = 22300$ PSI

A E T R O N
COVINA PLANT COVINA, CALIFORNIA
A DIVISION OF AEROJET-GENERAL CORPORATION

INPUT HG PUMP OUTLET (I), SL-1 PAGE 1

WIND IN X DIRECTION = -0. LBS/FT WIND IN Z DIRECTION = -0. LBS/FT

NO. OF BRANCHES = 1 NO. OF STOPS = -0 NO. OF CONCENTRATED WEIGHTS = -0

BRANCHES

BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.
1	1	8						

PAGE 5-4

ALLOWANCES AT ANCHORS

ANCHOR	DEFLECTIONS--INCHES DX	DY	DZ	ROTATIONS-DEGREES PHIX	PHIY	PHIZ
1	-0.0130	0.0320	0.0220	-0.	-0.	-0.
2	-0.	-0.	0.0180	-0.	-0.	-0.

MEMBERS

MEM	NPL	ALPHA	RADIUS LENGTH	OD	TH	WT	POIS	EH	EE	TEMP	PHI	NQD	PRES
1	2	270.00	0.29	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.
2	2	270.00	0.25	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	90.00	4	-0.
3	2	0.	0.98	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.
4	2	90.00	-0.25	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	90.00	2	-0.
5	2	270.00	1.13	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.
6	2	0.	-0.25	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.
7	2	180.00	1.00	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.

MATRIX HAS BEEN MODIFIED -- CALL CHAIN 2

TRESS INTENSIFICATION FACTORS

SIF 1 = 1.0000	SIF 2 = 1.0000	SIF 3 = 1.0000	SIF 4 = 1.0000
SIF 5 = 1.0000	SIF 6 = 1.0000	SIF 7 = 1.0000	SIF

ANCHOR	POINT	THERMAL EXPANSIONS IN INCHES -		
2	8	DX = -0.066776	DY = 0.	DZ = 0.008125

A E T R O N

COVINA PLANT COVINA, CALIFORNIA

A DIVISION OF AEROJET-GENERAL CORPORATION

OUTPUT HG PUMP OUTLET (I), SL-1

THE MAXIMUM STRESS IS 4723.3161 PSI AT POINT 8 EXCLUDING STRESSES AT JUNCTIONS

REACTIONS OF ANCHORS ON PIPE

		FT-LBS			LBS		
ANCHOR	POINT	MX	MY	MZ	FX	FY	FZ
1	1	-0.672	-2.447	-0.758	-5.228	0.781	2.080
2	8	0.490	5.213	-0.738	5.228	-0.781	-2.080

A E T R O N

COVINA PLANT COVINA, CALIFORNIA

A DIVISION OF AEROJET-GENERAL CORPORATION

OUTPUT HG PUMP OUTLET (I), SL-1

POINT	CO-ORDINATES IN FEET X	Y	Z	PSI STRESS	ROTATION-DEGREES PHI X	PHI Y	PHI Z	DEFLECTION-INCHES DELT X	DELT Y	DELT Z
1	0.	0.	0.	2366.17	-0.	-0.	-0.	-0.0130	0.0320	0.0220
2	-0.29	0.	0.	2830.60	0.0146	0.0458	0.0107	-0.0231	0.0316	0.0233
3	-0.54	0.	0.25	2088.28	0.0378	0.1712	0.0285	-0.0250	0.0291	0.0370
4	-0.54	0.	1.23	2598.96	0.0431	0.1539	0.0531	0.0136	0.0200	0.0712
5	-0.79	0.	1.48	3302.48	0.0295	0.0022	0.0606	0.0102	0.0150	0.0831
6	-1.92	0.	1.48	1420.32	-0.0113	-0.1590	0.0413	-0.0290	0.0018	0.0616
7	-1.92	0.	1.23	708.43	-0.0057	-0.1494	0.0551	-0.0210	0.0014	0.0529
8	-1.92	0.	0.23	4723.32	0.0000	-0.0000	-0.0000	-0.0000	-0.0000	0.0180

51658

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

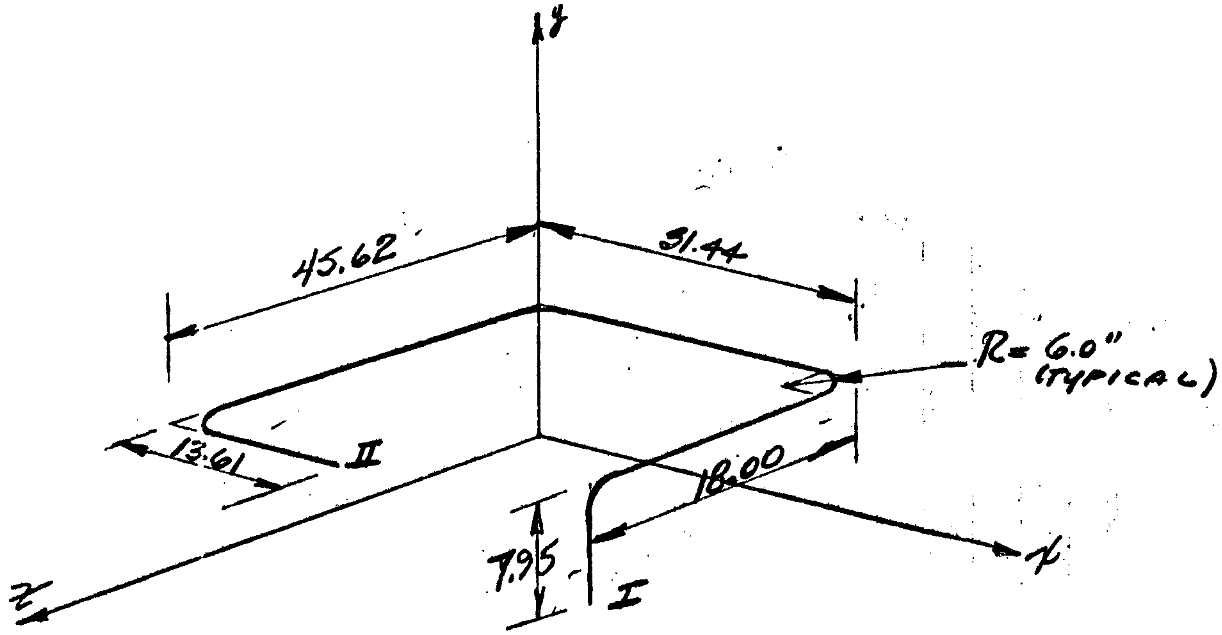
QUADRILLE WORK SHEET

DATE

SUBJECT TURBINE H_2 INLET (II), SL-1 PIPING FLEXIBILITY CALC. (THERMAL)

BY

WORK ORDER



FIXITY AT BOTH ENDS

D_o = 1.75 INCHES

WALL THICKNESS = 0.120 IN.

TEMP. = 1300 °F

$E = 19.50 \times 10^6$ PSI

$\alpha = 11.0 \times 10^{-6}$ IN/IN-°F

END MOVEMENTS

POINT I

$\delta_x = 0.142''$
$\delta_y = 0.112''$
$\delta_z = 0$
$\theta_x = \theta_y = \theta_z = 0$

POINT II

$\delta_x = -0.098''$
$\delta_y = 0.006''$
$\delta_z = 0.100''$
$\theta_x = -.0070$ RADIANS
$\theta_y = 0$
$\theta_z = 0$

$S_{ALL} = 1.25 S_c + 0.25 S_H = 1.25(18750) + 0.25(4000)$

$S_{ALL} = 24,400$ PSI

A E T R C N
COVINA PLANT COVINA, CALIFORNIA
A DIVISION OF AEROJET-GENERAL CORPORATION

INPUT TURBINE INLET -- THERMAL LOAD -- CASE 5 PAGE 1

WIND IN X DIRECTION = -0. LBS/FT WIND IN Z DIRECTION = -0. LBS/FT

NO. OF BRANCHES = 1 NO. OF STOPS = -0 NO. OF CONCENTRATED WEIGHTS = -0

BRANCHES

BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.
1	1	14						

ALLOWANCES AT ANCHORS

ANCHOR	DEFLECTIONS-INCHES DX	DY	DZ	ROTATIONS-DEGREES PHIX	PHIY	PHIZ
1	1.4200000E-01	1.1200000E-01	-0.	-0.	0.	-0.
2	-9.7999998E-02	5.9999999E-03	1.1000000E-01	-6.9999999E-03	0.	-0.

MEMBERS

MEM	APL	ALPHA	RADIUS LENGTH	CC	TH	WT	POIS	EH	EE	TEMP	PHI	NQD	EC
1	1	0.	0.16	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
2	1	90.00	-0.50	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	90.00	2	-0.
3	1	270.00	0.25	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
4	1	270.00	0.25	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
5	2	180.00	0.50	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	90.00	3	-0.
6	2	270.00	0.81	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
7	2	270.00	0.81	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
8	2	270.00	0.50	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	90.00	4	-0.
9	2	0.	1.40	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
10	2	0.	1.40	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
11	2	0.	0.50	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	90.00	1	-0.
12	2	90.00	0.07	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.
13	2	90.00	0.57	1.75	0.095	-0.	0.300	0.1950E 08	0.1100E-04	1230.	-0.	-0	-0.

STRESS INTENSIFICATION FACTORS

```
SIF  1 = 0.09999999E 01   SIF  2 = 0.09999999E 01   SIF  3 = 0.09999999E 01   SIF  4 = 0.09999999E 01
SIF  5 = 0.09999999E 01   SIF  6 = 0.09999999E 01   SIF  7 = 0.09999999E 01   SIF  8 = 0.09999999E 01
SIF  9 = 0.09999999E 01   SIF 10 = 0.09999999E 01   SIF 11 = 0.09999999E 01   SIF 12 = 0.09999999E 01
SIF 13 = 0.09999999E 01   SIF
```

INPUT TO MATRIX

```
C  1 = 0.11637741E 02     C  2 = 0.                  C  3 =-0.14753181E-00     C  4 =-0.15730579E 01
C  5 = 0.11642371E 03     C  6 =-0.12372325E 03      C  7 =-0.28077941E 01     C

C  1 = 0.                 C  2 = 0.11473717E 02      C  3 = 0.14753177E-00     C  4 =-0.11194856E 03
C  5 =-0.14753177E 01     C  6 = 0.96621253E 02      C  7 = 0.                 C

C  1 =-0.14753181E-00     C  2 = 0.14753177E-00      C  3 = 0.11720339E 02     C  4 = 0.12317073E 03
C  5 =-0.99872269E 02     C  6 = 0.30483756E 01      C  7 = 0.                 C

C  1 =-0.15730579E 01     C  2 =-0.11194856E 03      C  3 = 0.12317073E 03     C  4 = 0.24390129E 04
C  5 =-0.10469142E 04     C  6 =-0.91664847E 03      C  7 = 0.23643302E 01     C

C  1 = 0.11642371E 03     C  2 =-0.14753177E 01      C  3 =-0.99872269E 02     C  4 =-0.10469142E 04
C  5 = 0.20249079E 04     C  6 =-0.12524935E 04      C  7 =-0.44355305E 03     C

C  1 =-0.12372325E 03     C  2 = 0.96621253E 02      C  3 = 0.30483756E 01     C  4 =-0.91664847E 03
C  5 =-0.12524935E 04     C  6 = 0.21428271E 04      C  7 =-0.47519449E 03     C
```

N CALCULATED CONSTANT	ACTUAL CONSTANT	N+1 CALCULATED CONSTANT	ACTUAL CONSTANT	N+2 CALCULATED CONSTANT	ACTUAL CONSTANT
-0.28C77392E 01	-0.28077941E 01	-0.61035156E-04	0.	0.15258789E-04	0.
0.23647460E 01	0.23643302E 01	-0.44355224E 03	-0.44355305E 03	-0.47519629E 03	-0.47519449E 03

ANCHOR	POINT	THERMAL EXPANSIONS IN INCHES -		
2	14	DX =-0.24123452E-00	DY = 0.10756348E-00	DZ = 0.37375262E-00

SOLUTIONS TO MATRIX

R 1 =-0.33877891E 03 R 2 = 0.51016350E 03 R 3 =-0.25911680E 03 R 4 = 0.14258742E 02
R 5 =-0.12907889E 02 R 6 =-0.43862411E 02 R

A E T R O N

COVINA PLANT COVINA, CALIFORNIA

A DIVISION OF AEROJET-GENERAL CORPORATION

OUTPUT TURBINE INLET -- THERMAL LOAD -- CASE 5 PAGE 1

STRESS VALUES INTENSIFIED

R' = 1.21 DUE TO t = .120 RATHER THAN .095 (ONLY END LOADS CORRECTED)

AT POINT 1 THE STRESS IS 4816.2059 PSI ON MEMBER 1

DIRECTION OR PLANE	CO-ORDINATES IN FEET	FORCE-LBS	MOMENT--FT-LBS	DEFLECTION-INCHES	ROTATION-DEGREES
X	0.	~~14.2587~~ 17.3	~~-29.2337~~ -35.4	0.1420	-0.
Y	0.	~~-12.9079~~ -15.6	~~-71.0480~~ -86.0	0.1120	-0.
Z	0.	~~-43.8624~~ -53.1	~~12.5495~~ 15.1	-0.	-0.

AT POINT 2 THE STRESS IS 4694.4970 PSI ON MEMBER 2

DIRECTION OR PLANE	CO-ORDINATES IN FEET	FORCE-LBS	MOMENT--FT-LBS	DEFLECTION-INCHES	ROTATION-DEGREES
X	0.	14.2587	-22.1061	0.1419	-0.0104
Y	0.1625	-12.9079	-71.0480	0.1384	-0.0374
Z	0.	-43.8624	14.8666	-0.0002	0.0056

AT POINT 3 THE STRESS IS 4200.1760 PSI ON MEMBER 3

DIRECTION OR PLANE	CO-ORDINATES IN FEET	FORCE-LBS	MOMENT--FT-LBS	DEFLECTION-INCHES	ROTATION-DEGREES
X	0.	14.2587	6.2791	0.1570	-0.0319
Y	0.6625	-12.9079	-63.9187	0.2160	-0.2431
Z	-0.5000	-43.8624	21.9959	-0.0845	0.0400

AT POINT 4 THE STRESS IS 4017.5606 PSI ON MEMBER 4

DIRECTION OR PLANE	CO-ORDINATES IN FEET	FORCE-LBS	MOMENT--FT-LBS	DEFLECTION-INCHES	ROTATION-DEGREES
X	0.	14.2587	9.5061	0.1708	-0.0269
Y	0.6625	-12.9079	-60.3540	0.2144	-0.2819
Z	-0.7500	-43.8624	21.9959	-0.1251	0.0579

NOTE: END LOADS WERE CORRECTED BY MULTIPLYING "TYPED VALUES" BY R' TO CORRECT FOR CHANGED PIPE WALL THICKNESS.

A E T R C N
COVINA PLANT COVINA, CALIFORNIA
A DIVISION OF AEROJET-GENERAL CORPORATION

OUTPUT TURBINE INLET -- THERMAL LOAD -- CASE 5
STRESS VALUES INTENSIFIED

AT POINT 5 THE STRESS IS 3849.2994 PSI ON MEMBER 5

DIRECTION OR PLANE	CO-ORDINATES IN FEET	FORCE-LBS	MOMENT--FT-LBS	DEFLECTION-INCHES	ROTATION-DEGREES
X	0.	14.2587	12.7330	0.1865	-0.0200
Y	0.6625	-12.9079	-56.7893	0.2131	-0.3184
Z	-1.0000	-43.8624	21.9959	-0.1657	0.0757

AT POINT 6 THE STRESS IS 2297.1360 PSI ON MEMBER 6

DIRECTION OR PLANE	CO-ORDINATES IN FEET	FORCE-LBS	MOMENT--FT-LBS	DEFLECTION-INCHES	ROTATION-DEGREES
X	-0.5000	14.2587	19.1870	0.1460	0.0245
Y	0.6625	-12.9079	-27.7287	0.2012	-0.4822
Z	-1.5000	-43.8624	15.5420	-0.2923	0.1300

AT POINT 7 THE STRESS IS 1319.4910 PSI ON MEMBER 7

DIRECTION OR PLANE	CO-ORDINATES IN FEET	FORCE-LBS	MOMENT--FT-LBS	DEFLECTION-INCHES	ROTATION-DEGREES
X	-1.3100	14.2587	19.1870	0.0145	0.0749
Y	0.6625	-12.9079	7.7999	0.1770	-0.5024
Z	-1.5000	-43.8624	5.0866	-0.3771	0.1508

AT POINT 8 THE STRESS IS 2950.5086 PSI ON MEMBER 8

DIRECTION OR PLANE	CO-ORDINATES IN FEET	FORCE-LBS	MOMENT--FT-LBS	DEFLECTION-INCHES	ROTATION-DEGREES
X	-2.1200	~~14.2587~~	~~19.1870~~	-0.1170	0.1252
Y	0.6625	~~-12.9079~~	~~43.3204~~	0.1511	-0.4507
Z	-1.5000	~~-43.8624~~	~~-5.3603~~	-0.4592	0.1505
		17.3	23.2		
		15.6	52.3		
		-53.1	6.5		

OUTPUT TURBINE INLET -- THERMAL LOAD -- CASE 5

STRESS VALUES INTENSIFIED

AT POINT 9 THE STRESS IS 3753.6725 PSI ON MEMBER 9

DIRECTION OR PLANE	CO-ORDINATES IN FEET	FORCE-LBS	MOMENT--FT-LBS	DEFLECTION-INCHES	ROTATION-DEGREES
X	-2.6200	14.2587	12.7330	-0.2324	0.1735
Y	0.6625	-12.9079	58.1302	0.1197	-0.2483
Z	-1.0000	-43.8624	-11.8227	-0.4182	0.1280

AT POINT 10 THE STRESS IS 2493.3330 PSI ON MEMBER 10

DIRECTION OR PLANE	CO-ORDINATES IN FEET	FORCE-LBS	MOMENT--FT-LBS	DEFLECTION-INCHES	ROTATION-DEGREES
X	-2.6200	14.2587	-5.3509	-0.2787	0.1864
Y	0.6625	-12.9079	38.1537	0.0653	-0.0802
Z	0.4010	-43.8624	-11.8227	-0.1908	0.0743

AT POINT 11 THE STRESS IS 1975.3319 PSI ON MEMBER 11

DIRECTION OR PLANE	CO-ORDINATES IN FEET	FORCE-LBS	MOMENT--FT-LBS	DEFLECTION-INCHES	ROTATION-DEGREES
X	-2.6200	14.2587	-23.4349	-0.2860	0.1361
Y	0.6625	-12.9079	18.1772	0.0163	0.0182
Z	1.8020	-43.8624	-11.8227	0.0366	0.0206

AT POINT 12 THE STRESS IS 1995.7946 PSI ON MEMBER 12

DIRECTION OR PLANE	CO-ORDINATES IN FEET	FORCE-LBS	MOMENT--FT-LBS	DEFLECTION-INCHES	ROTATION-DEGREES
X	-2.1200	14.2587	-29.8888	-0.2010	0.0544
Y	0.6625	-12.9079	-10.8833	0.0061	0.0392
Z	2.3020	-43.8624	-5.3688	0.1133	0.0020

A E T R O N

COVINA PLANT COVINA, CALIFORNIA

A DIVISION OF AEROJET-GENERAL CORPORATION

OUTPUT TURBINE INLET -- THERMAL LOAD -- CASE 5

STRESS VALUES INTENSIFIED

AT POINT 13 THE STRESS IS 2056.8235 PSI ON MEMBER 13

DIRECTION OR PLANE	CO-ORDINATES IN FEET	FORCE-LBS	MOMENT--FT-LBS	DEFLECTION-INCHES	ROTATION-DEGREES
X	-2.0525	14.2587	-29.8888	-0.1900	0.0479
Y	0.6625	-12.9079	-13.8440	0.0061	0.0371
Z	2.3020	-43.8624	-4.4975	0.1127	0.0012

AT POINT 14 THE STRESS IS 3030.3294 PSI ON MEMBER 13

DIRECTION OR PLANE	CO-ORDINATES IN FEET	FORCE-LBS	MOMENT--FT-LBS	DEFLECTION-INCHES	ROTATION-DEGREES
X	-1.4858	~~14.2587~~ 17.3	~~-29.8888~~ -36.2	-0.0980	-0.0070
Y	0.6625	~~-12.9079~~ -15.6	~~-38.7009~~ -46.7	0.0060	0.0000
Z	2.3020	~~-43.8624~~ -53.1	~~-2.8174~~ 3.4	0.1100	-0.0000

THE MAXIMUM STRESS IS 4816.2059 PSI AT POINT 1

AEROJET GENERAL TIRE GENERAL

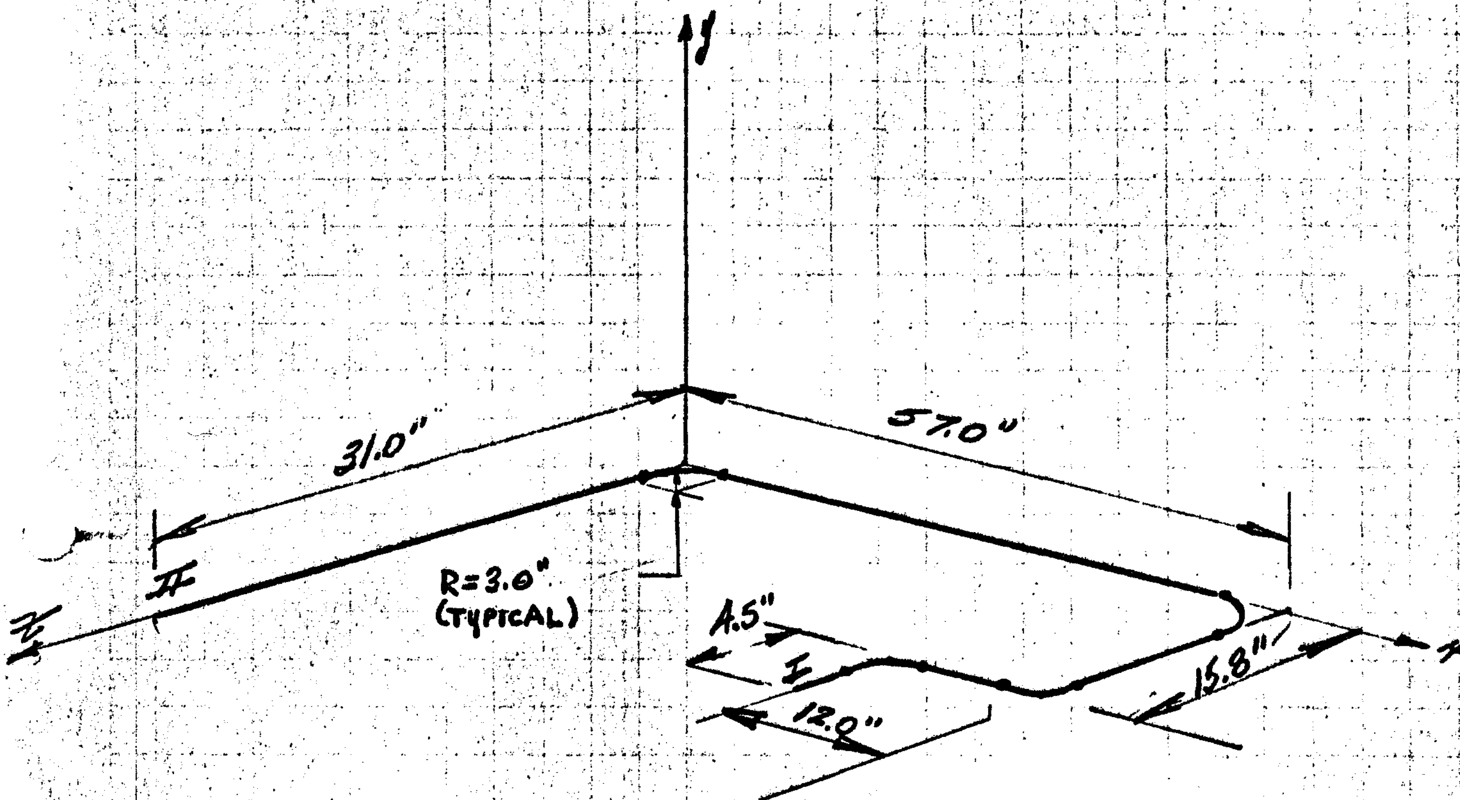
AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

QUADRILLE WORK SHEET

PAGE 69 OF ____ PAGES
DATE ____
WORK ORDER ____

SUBJECT FLOW CONTROL VALVE HG INLET (I), SL-1 PIPING FLEXIBILITY CALC.

BY ____



FIXITY AT I & II

$D_o = 0.75''$

WALL THICKNESS = 0.035"

TEMP. = 515°F, ΔT = 445°F

$E = 28.5 \times 10^6$ PSI

$\alpha = 6.53 \times 10^{-6}$ IN/IN.-°F

ALL BENDS ARE 90 BENDS

END MOVEMENTS

POINT I

$\delta x = 0$

$\delta y = -.032''$

$\delta z = -.022''$

$\theta x = \theta y = \theta z = 0$

POINT II

$\delta x = 0$

$\delta y = 0$

$\delta z = -.031$

$\theta x = \theta y = \theta z = 0$

$S_{ALL.} = 1.25\, S_c + 0.25\, S_H = 1.25(15000) + 0.25(14500) = 22300$ PSI $= S_{ALL.}$

INPUT HG LINE TO FLOW CONTROL VALVE(I) PAGE 1

WIND IN X DIRECTION = -0. LBS/FT WIND IN Z DIRECTION = -0. LBS/FT

NO. OF BRANCHES = 1 NO. OF STOPS = -0 NO. OF CONCENTRATED WEIGHTS = -0

BRANCHES

BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.	BRANCH	BEG. PT.	END PT.
1	1	10						

ALLOWANCES AT ANCHORS

ANCHOR	DEFLECTIONS-INCHES DX	DY	DZ	ROTATIONS-DEGREES PHIX	PHIY	PHIZ
1	-0.	-0.0320	-0.0220	-0.	-0.	-0.
2	-0.	-0.	-0.0310	-0.	-0.	-0.

MEMBERS

MEM	APL	ALPHA	RADIUS LENGTH	OD	TH	WT	POIS	EH	EE	TEMP	PHI	MOD	PRES
1	2	180.00	0.13	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.
2	2	270.00	-0.25	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	90.00	4	-0.
3	2	90.00	0.50	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.
4	2	90.00	0.25	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	90.00	2	-0.
5	2	180.00	0.82	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.
6	2	180.00	0.25	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	90.00	3	-0.
7	2	270.00	4.25	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.
8	2	270.00	0.25	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	90.00	4	-0.
9	2	0.	2.33	0.75	0.035	-0.	0.300	0.2850E 08	0.6530E-05	445.	-0.	-0	-0.

MATRIX HAS BEEN MODIFIED -- CALL CHAIN 2

STRESS INTENSIFICATION FACTORS

SIF 1 = 1.0000	SIF 2 = 1.0000	SIF 3 = 1.0000	SIF 4 = 1.0000
SIF 5 = 1.0000	SIF 6 = 1.0000	SIF 7 = 1.0000	SIF 8 = 1.0000
SIF 9 = 1.0000	SIF		

ANCHOR PCINT THERMAL EXPANSIONS IN INCHES -

ANCHOR	PCINT	DX	DY	DZ
2	10	DX = -0.130763	DY = 0.	DZ = 0.031000

A E T R O N

COVINA PLANT COVINA, CALIFORNIA

A DIVISION OF AEROJET-GENERAL CORPORATION

OUTPUT HG LINE TO FLOW CONTROL VALVE(I)

THE MAXIMUM STRESS IS 3037.2858 PSI AT POINT 10 EXCLUDING STRESSES AT JUNCTIONS

REACTIONS OF ANCHORS ON PIPE

		FT-LBS			LBS		
ANCHOR	POINT	MX	MY	MZ	FX	FY	FZ
1	1	-0.063	2.289	0.082	-1.929	-0.055	0.162
2	10	0.112	-3.396	0.126	1.929	0.055	-0.162

OUTPUT HG LINE TO FLOW CONTROL VALVE(I)

	CO-ORDINATES IN FEET			PSI	ROTATION-DEGREES			DEFLECTION-INCHES		
POINT	X	Y	Z	STRESS	PHI X	PHI Y	PHI Z	DELT X	DELT Y	DELT Z
1	0.	0.	0.	2047.33	-0.	-0.	-0.	-0.	-0.0320	-0.0220
2	-0.00	0.	-0.13	1831.96	0.0004	-0.0156	-0.0008	0.0002	-0.0320	-0.0264
3	0.25	0.	-0.38	1438.24	0.0018	-0.0913	-0.0038	0.0113	-0.0321	-0.0316
4	0.75	0.	-0.38	1512.23	0.0033	-0.1387	-0.0069	0.0287	-0.0326	-0.0196
5	1.00	0.	-0.63	1120.15	0.0041	-0.2050	-0.0115	0.0470	-0.0329	-0.0197
6	1.00	0.	-1.44	318.51	0.0043	-0.2265	-0.0200	0.0850	-0.0321	-0.0482
7	0.75	0.	-1.69	768.99	0.0040	-0.1985	-0.0246	0.0877	-0.0307	-0.0679
8	-3.50	0.	-1.69	1380.79	-0.0059	0.0937	-0.0261	-0.0604	-0.0039	-0.1271
9	-3.75	0.	-1.44	988.78	-0.0063	0.1537	-0.0219	-0.0621	-0.0023	-0.1122
10	-3.75	0.	0.89	3037.29	0.0000	0.0000	-0.0000	0.0000	-0.0000	-0.0310

REFERENCES

1. Drawing No. 092800, "Mercury Loop Assembly -1A"
2. Code for Pressure Piping, ASA B31.1 - 1955
3. ASME Boiler and Pressure Vessel Code
4. Design of Piping Systems, the M. W. Kellogg Co.

TM 340:64-1-186

FLANGE STRESS ANALYSIS - PCS-1, PCS-2

Sections of the following TM Applicable to the TAA

- - - - - - - -

Or:

All references in this Technical Memorandum to Joints 3 and 6 apply to the TAA.

DIVISION SNAP-8

TM 340:64-1-186

DATE 30 June 1964

W.O. 0743-02-2000

TECHNICAL MEMORANDUM

AUTHOR(S): A. Levitsky

TITLE: FLANGE STRESS ANALYSIS - PCS-1, PCS-2

ABSTRACT

The stress analysis presented in this memorandum indicates the bolt loads required to adequately seat the gasket and to resist the operating pressure without leakage. Also included are the critical margins of safety in the bolts and the collars. The design and analysis used conform, in general, to the requirements of the ASME Unfired-Pressure-Vessel Code.

APPROVED:

DEPARTMENT HEAD P. I. Wood

P. I. Wood

TABLE OF CONTENTS

I. INTRODUCTION

The PCS-1 assembly was designed so that components could be removed, and replaced quickly and easily. Toward this objective, piping connections at all major components incorporate "loose-type" bolted flanges with welding "lips." The option to seal weld the flanges enables the piping assemblies to be welded up for a long endurance test, as well as providing a backup in case of flange leakage.

The gaskets and the sealing flanges are of proprietary design (Aeroquip), and, therefore, no analysis of these elements are presented in this report. The bolt loads required to seat the gasket, and to maintain the seal under operating pressure, have been supplied by the vendor. The subsequent design of the bolts and collars are based on these values.

Materials for bolts and collars were chosen with the objective of maintaining low creep rates and compatible coefficients of thermal expansion. This results in increased seal reliability over extended steady-state periods of operation, as well as under transient conditions.

II. CONCLUSIONS AND RECOMMENDATIONS

A. The method used in this analysis is conservative, since it is based on the ASME Unfired-Pressure-Vessel Code, which forms design criteria for systems with expected operational life considerably beyond 10,000 hours. In addition, the elements making up the connections are considerably stronger than indicated in the Margin-of-Safety Summary for reasons as indicated below:

1. The collars have a thickened section adjacent to the flange which was not taken into account in the analysis.

2. The bolt margins of safety are based on combined stresses, which include the effects of torsional shear stress. Test data, however, indicates that the tensile load in a torqued up bolt just before failure is the same as that in a bolt under simple tension before failure.

B. Analysis indicates that the elastic deflections of the collars in flanged joints are considerably greater than that of the bolts. This type of design has the following advantages:

1. The flanged connection is relatively insensitive to relaxation due to creep in the bolt. Any strain in the bolt is small compared to the total deflection of the collar, and, consequently, the response of the system to creep in the bolts is such as to cause negligible change in the bolt load.

2. The differential expansions in the system due to radial temperature gradients and different materials cause negligible changes in the bolt load. This is particularly important during the startup cycle when the bolts are at lower temperature than the collars.

Additional margin against leakage is provided by the elasticity in the conically-shaped "Conoseal" gasket.

III. SYMBOLS

A	Outside diameter of collar (inches)
A_r	Bolt cross-sectional area (square inches)
B	Inside diameter of flange (inches)
b	Outside diameter of hub portion of collar (inches)
C	Bolt circle diameter (inches)
C.F.	Moment correction factor for bolt spacing
D	Bolt diameter (inches)
D_m	Bolt minor diameter (inches)
E	Modulus of elasticity (psi)
f_{FA}	Allowable collar stress at ambient temperature (psi)
f_{FO}	Allowable collar stress at operating temperature (psi)
G	Diameter at location of gasket-load reaction (inches)
H	Total hydrostatic end force (pounds)
H_D	Hydrostatic end force on area inside of flange (pounds)
h_D	Radial distance from bolt circle to inside tube surface (inches)
H_g	Difference between flange-design bolt load and hydrostatic end force (pounds)
h_g	Radial distance from the gasket load to the bolt circle (inches)
H_T	Difference between total hydrostatic end force and end force on area inside of flange (pounds)
h_T	Radial distance from bolt circle to circle on which H_T acts (inches)
K	Ratio of outside to inside diameter of collar
k_c	Axial collar spring constant (pounds per inch)
k_s	Axial bolt spring constant (pounds per inch)

L	Half the effective elastic length of bolt (inches)
M	Maximum collar moment corrected for bolt spacing (inch-pounds)
M_a	Moment under bolting-up conditions (inch-pounds)
M_D	Component of moment due to hydrostatic end force (inch-pounds)
M_G	Component of moment due to Hg (inch-pounds)
M_o	Total moment acting upon the flange (inch-pounds)
M_T	Component of moment due to H_T (inch-pounds)
P	Bolt tensile load (pounds)
p	Maximum operating pressure (psi)
S	Combined stress (psi)
T	Bolt torque (inch-pounds)
t	Collar thickness (inches)
T_t	Torque transmitted (inch-pounds)
ΔT	Operating temperature minus ambient temperature (°F)
UFOS	Ultimate Factor of Safety
W	Flange-design bolt load (pounds)
ΔW	Change in the total bolt load (pounds)
W_{M1}	Minimum required bolt load to maintain seal (pounds)
Y	Tangential bending coefficient
y	Axial deflection (inches)
YFOS	Yield Factor of Safety
α	Deflection coefficient for a circular plate
β	Linear coefficient of thermal expansion (in/in - °F)
$\Delta\delta$	Differential thermal expansion (inches)
ϵ	Poissons ratio
δ	Thermal expansion (inches)
σ	Normal stress (psi)
$\Delta\sigma$	Change in normal stress (psi)
τ	Torsional shear stress (psi)

IV. DISCUSSION AND RESULTS

A flanged joint assembly may be idealized as two elastically coupled bodies; the bolts as one body, and the flanges, collars and gasket as the other. A model of the complete joint may then be represented as two springs with different lengths and stiffnesses. When the joint is tightened, the bolt "spring" is put into tension and the flange-collar-gasket "spring" into compression, thus eliminating the initial length difference. This action presses the flanges against the gasket, sealing the joint. A flanged joint under pressure will not leak as long as the gasket tensile strain, resulting from internal pressure, does not offset the compressive strain due to initial bolt tightening. The above simplified model forms the basis for this analysis. In addition, the effects of temperature and creep were checked separately, and found to be negligible.

The Unfired Pressure Vessel Code provides two criteria which must be satisfied in order to maintain a gasketed joint free from leakage. The bolt load should be sufficient to seat the gasket, and also to withstand the internal pressure, while still supplying sufficient gasket sealing pressure to prevent leakage. Since the "Conoseal" flanged assembly is a proprietary design, bolt tightening loads sufficient to satisfy the above criteria were obtained from the vendor.

For most services the effects of direct pressure stresses and the discontinuity effects due to these may be neglected. An adequate representation is obtained by assuming the collar subjected to a uniformly distributed moment due to the effects of the end pressure load, gasket load, and bolt load. The bolt load is assumed to be unaffected by pressure changes with all strains elastic in nature and unaffected by creep or yielding. The above approach, which forms part of the ASME Unfired Pressure Vessel Code, was utilized in the design of the flanged assemblies.

As the flanged connections heat up and approach operating temperature, several effects take place tending to change the bolt loads. The moduli of elasticity drop, radial thermal gradients appear (particularly in startup), and where more than one material is used in the flange assembly, differential thermal expansion effects take place. In addition, localized yielding and creep occur, particularly where high temperatures and cyclical operation exist. The "Conoseal" flange design incorporates sufficient pretightening of the assembly to compensate for bolt-load reduction due to these effects. In general, good flange design will incorporate high elastic strains in the bolts and flanges combined with high material creep resistance.

Where cyclical loadings are present, care should be taken to eliminate or reduce all possible stress raisers. Toward this objective generous corner radii were incorporated where possible, particularly in the highly stressed areas. Stud bolts with unthreaded portions machined to the root diameter were used in preference to headed bolts.

Flanged connections subjected to thermal expansion effects may be treated on a "stress range" basis similar to piping thermal stresses. Since the thermal piping stresses at the flanges in PCS-1 were low, no formal thermal stress analysis was performed on the flanges. Good design, however, indicated the desirability of keeping flanged joints to a minimum, and where possible, locating them in the area of low moments.

The bolt preload was made greater than any resultant bolt loads due to pressure. This assures that there will be no separation of the parts or extension of the bolts; e.g., no increase in the bolt tension. The preloading is also beneficial in increasing the resistance to bolt fatigue and in providing a locking effect.

Due to the elastic action of the nut, the threads near the base of the nut take more load than the top threads. The nuts are made of a softer material than the bolt, allowing the highly loaded nut threads to relieve plastically, thus shifting some of the load to the less loaded top threads.

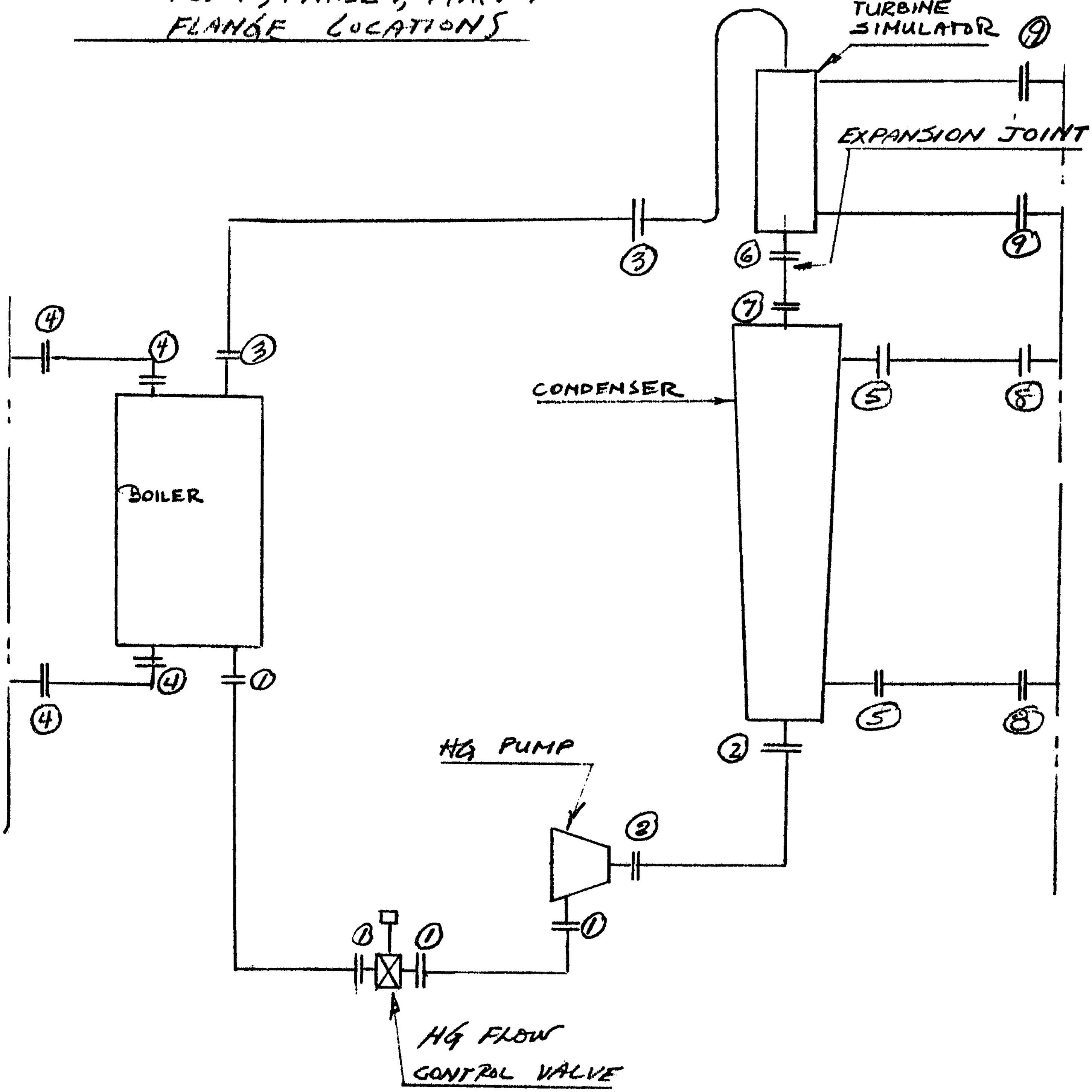
The torque required to give the necessary preload was calculated using the following formula:

$$\text{Torque (in-lb)} = 0.2 \times \text{bolt diameter (in.)} \times \text{bolt tension (lb)}$$

Tests on large numbers of bolts confirm the validity of the above torque coefficient. It has been found that the mean deviation among samples tested is under 10%. The formula is based upon the fact that 90% or more of the applied torque is consumed in friction on the bearing face of the bolt head or nut and on the bearing face of the mating threads, and produces no tension whatever. The value of the torque coefficient can be verified mathematically by assuming a coefficient of friction of 0.15 and a nut width of 1½ diameters.

When a nut is tightened on a bolt, a torsional shear stress as well as a tensile stress is induced in the bolt. It results from the friction between the threads as the nut is turned, and consumes about 45% of the applied torque. The combined tensile and shear stresses result in a normal stress which is higher than the bolt axial tensile stress. The ultimate strength of the bolt, however, is not affected by the added shear stress. Test data indicates that if a bolt were tightened to a point just below failure, the direct tensile load would be equal to that required to fail the bolt by applying direct axial tension.

PCS-1, PHASE 1, PART 1
FLANGE LOCATIONS



NOTES

1. IN PCS-1, PHASE 1, PART 2 TAA IS SUBSTITUDED FOR THE TURBINE SIMULATOR.
2. ONLY MAJOR COMPONENTS ARE SHOWN.

DESIGN CONDITIONS

Joint No.	Design Temp. (°F.)	Design Pressure (psig)	Materials: Collar	Flange	Bolt	Gasket	Nut
1	515	355	A-286	9CR-1Mo	Inconel X	SS, Type 321	A-286
2	505	7.5*	A-286	9CR-1Mo	Inconel X	SS, Type 321	A-286
3	1280	285	Inconel X	SS, Type 316	Inconel X	SS, Type 321	A-286
4	1248ø	26ø	Inconel X	SS, Type 316	Inconel X	SS, Type 321	A-286
5	496Δ	38Δ	A-286	SS, Type 316) 9CR-1Mo)	Inconel X	SS, Type 321	A-286
6	680	7.5*	A-286	9CR-1Mo	Inconel X	SS, Type 321	A-286
7	680	7.5*	A-286	9CR-1Mo	Inconel X	SS, Type 321	A-286
8	496Δ	38Δ	A-286	SS, Type 316	Inconel X	SS, Type 321	A-286
9	(570 (1160	(16 (0	Inconel X	(SS, Type 316 (9CR-1Mo	Inconel X	SS, Type 321	A-286

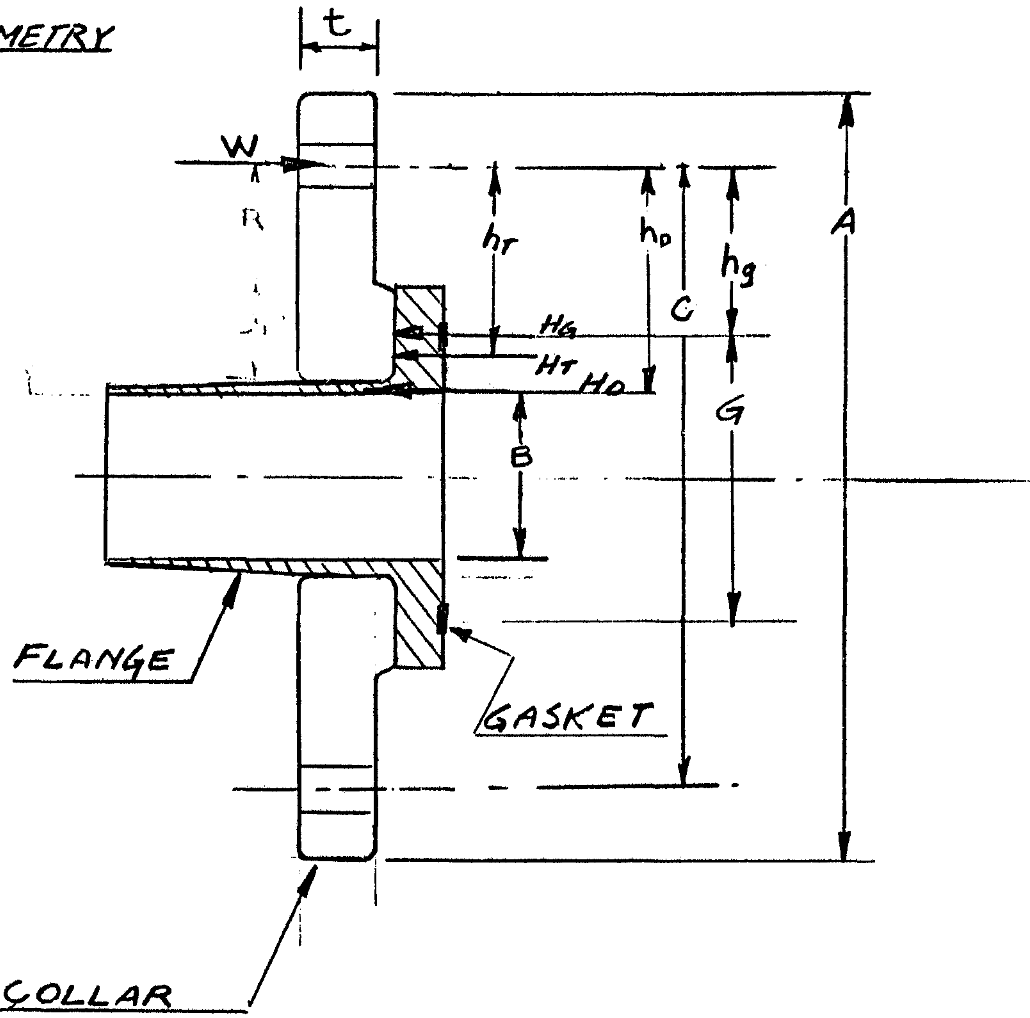
NOTES:

1. * For joints 2, 6 & 7 - Design pressure was taken as 7.5 psig for purposes of computation, since actual pressures are negligible.

2. Δ By inspection, critical pressure-temp. condition exists at condenser NaK inlet.

3. ø By inspection critical pressure-temp. condition exists at boiler NaK inlet.

GEOMETRY



GEOMETRY (Continued)

Joint No.	A	B	C	G	t	h_o	h_G	h_T
1	2.480	0.680	1.918	0.941	0.30	0.619	0.489	0.554
2	2.730	0.930	2.168	1.186	0.30	0.619	0.491	0.555
3	4.669	1.560	3.669	2.123	0.55	1.054	0.773	0.913
4	4.919	1.902	3.919	2.373	0.55	1.008	0.773	0.891
5	4.919	1.902	3.919	2.373	0.55	1.008	0.773	0.891
6	7.058	3.500	6.246	4.343	0.60	1.373	0.951	1.162
7	7.683	4.124	6.871	4.843	0.60	1.373	1.014	1.193
8	4.919	1.902	3.919	2.373	0.55	1.008	0.773	0.891
9	2.730	0.930	2.168	1.186	0.50	0.619	0.491	0.555

NOTES:

1. Refer to Page 8
2. All dimensions in inches.
3. $h_G = 0.5\ (C-G)$
4. $h_T = 0.5\ (h_D = h_G)$

TORQUE LIMITATIONS VENDOR DATA

JOINT NO.	MALE FLANGE PART NO.	FEMALE FLANGE PART NO.	NO. OF BOLTS	BOLT DIA. (IN.)	TORQUE REQ'D TO MAINTAIN SEAL (IN/LB)	TORQUE REQ'D TO SEAT GASKET (IN-LB)	MAXIMUM ALLOWABLE TORQUE (IN-LB)
1	MFC59802-7	MFC59803-3	6	1/4	6	9	40
2	MFC59802-9	" -5	"	1/4	6	10	25
3	MFC59801-1	" -7	"	3/8	27	35	180
4	MFC59801-3	" -9	"	3/8	29	39	85
5	MFC59802-1	" -1	"	3/8	29	39	125
6	MFC59802-3	" -11	"	3/8	51	68	215
7	MFC59802-5	" -13	"	3/8	57	75	145
8	MFC59802-1	" -9	"	3/8	29	39	125
9	MFC59802-13	" -5	"	3/8	6	10	25

NOTES:

1. Torque values do not include nut "free-spinning" torque.

2. Above values do not include any allowance for creep or thermal relaxation of bolt loadings.

BOLT LOADS - BASED ON VENDOR'S RECOMMENDED TORQUES

*Torque (in-lbs) = 0.2 x Bolt Diam. (in) x Bolt Tension (lbs)

$$T = 0.2 \times D \times P$$

$$P = \frac{T}{0.2 \times D}$$

For 6 Bolts $\qquad 6\,P = \frac{6T}{0.2 \times D} = \underline{\frac{30T}{D} = 6\,P}$

JOINT NO.	MINIMUM FORCE REQUIRED TO MAINTAIN SEAL (LBS)	MINIMUM FORCE REQUIRED TO SEAT GASKET (LBS)	MAXIMUM ALLOWABLE TOTAL BOLT LOAD (LBS)
1	720	1080	4800
2	720	1200	3000
3	2160	2800	14400
4	2320	3120	6800
5	2320	3120	10000
6	4080	5430	17200
7	4560	6000	11600
8	2320	3120	10000
9	480	800	2000

* Reference - ASME Handbook - Metals Engineering Design, O. J. Horger

RECOMMENDED TORQUE VALUES

JOINT	P TIGHTENING FORCE PER BOLT (LBS)	D DIA. (IN)	T TORQUE/BOLT (IN-LBS)
1	325	0.250	17
2	375	0.250	19
3	1800	0.375	135
4	850	0.375	64
5	1250	0.375	94
6	1450	0.375	109
7	1450	0.375	109
8	1250	0.375	94
9	250	0.375	19

NOTE:

1. $T = .2DP$
2. Values of "T" do not include "free-spinning" torque.
3. Tightening force per bolt were based on 75% of maximum allowable load per bolt (reference Page 17), except in Joints 1 and 2, where reduced values were used to meet the higher factor of safety requirements.

ALLOWABLE STRESSES

The general specification structural design criteria specifies the following factors of safety:

For tubing and fittings of greater than 1.50" diameter:

a. Proof Pressure (Yield) = 1.50 x Limit Pressure

b. Burst Pressure (Ultimate) = 2.50 x Limit Pressure

For flanged connections less than 1.50" diameter:

a. Proof Pressure (Yield) = 2.00 x Limit Pressure

b. Burst Pressure (Ultimate) = 4.00 x Limit Pressure

For flange design use YFOS = 1.5 and UFOS = 2.5:

COLLAR ALLOWABLE STRESSES

	AMBIENT TEMP. PROPERTIES					DESIGN TEMP. PROPERTIES				
JOINT NO.	ULT. STRESS (PSI)	YIELD STRESS (PSI)	ULT. STRESS ÷ UFOS (PSI)	YIELD STRESS ÷ YFOS (PSI)	ALLOWABLE STRESS (F_{FA}) (PSI)	ULT. STRESS (PSI)	YIELD STRESS (PSI)	ULT. STRESS ÷ UFOS (PSI)	YIELD STRESS ÷ YFOS (PSI)	ALLOWABLE STRESS (F_{FO}) (PSI)
1	130,000	85,000	51,800	56,700	51,800	121,000	80,000	48,300	53,200	48,300
2	130,000	85,000	51,800	56,700	51,800	121,000	80,000	48,300	53,200	48,300
3	155,000	100,000	62,000	66,700	62,000					*38,000
4	155,000	100,000	62,000	66,700	62,000					*35,000
5	130,000	85,000	51,800	56,700	51,800	121,000	80,000	48,300	53,200	48,300
6	130,000	85,000	51,800	56,700	51,800	117,000	77,000	46,800	51,300	46,800
7	130,000	85,000	51,800	56,700	51,800	117,000	77,000	46,800	51,300	46,800
8	130,000	85,000	51,800	56,700	51,800	121,000	80,000	48,300	53,200	48,300
9	155,000	100,000	62,000	66,700	62,000	147,000	93,000	58,800	62,000	58,800 △*63,000

1. * Allowable stress based on 0.1% creep in 10,000 hours.
2. △Allowable stress at 1160°F.

BOLT ALLOWABLE STRESSES

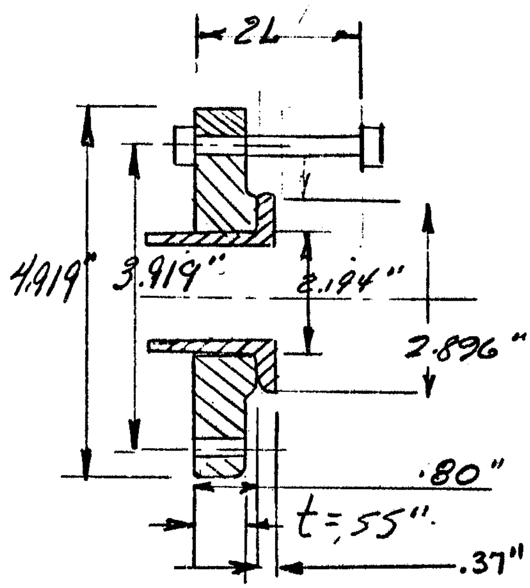
JOINT NO.	AMBIENT TEMP. PROPERTIES					DESIGN TEMP. PROPERTIES				
	ULT. STRESS (PSI)	YIELD STRESS (PSI)	ULT. STRESS ÷ UFOS (PSI)	YIELD STRESS ÷ YFOS (PSI)	ALLOWABLE STRESS (PSI)	ULT. STRESS (PSI)	YIELD STRESS (PSI)	ULT. STRESS ÷ UFOS (PSI)	YIELD STRESS ÷ YFOS (PSI)	ALLOWABLE STRESS (PSI)
1	155,000	100,000	62,000	66,700	62,000	150,000	95,000	60,000	63,300	60,000
2	155,000	100,000	62,000	66,700	62,000	150,000	95,000	60,000	63,300	60,000
3	155,000	100,000	62,000	66,700	62,000					*38,000
4	155,000	100,000	62,000	66,700	62,000					*35,000
5	155,000	100,000	62,000	66,700	62,000	150,000	95,000	60,000	63,300	60,000
6	155,000	100,000	62,000	66,700	62,000	144,000	91,000	57,600	60,600	57,600
7	155,000	100,000	62,000	66,700	62,000	144,000	91,000	57,600	60,600	57,600
8	155,000	100,000	62,000	66,700	62,000	150,000	95,000	60,000	63,300	60,000
9	155,000	100,000				147,000	93,000	59,000	62,000	59,000
										Δ*63,000

NOTES:

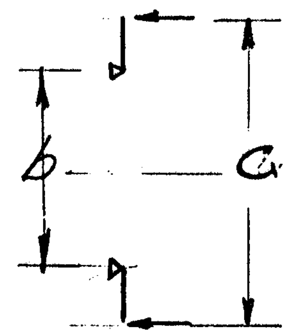
1. * Allowable stress based on 0.1% creep in 10,000 hours.
2. Δ Allowable stress at 1160°F.

CHECK SPRING CONSTANT OF COLLAR RELATIVE TO THAT OF BOLT. - ASSUME JOINT NO.4 AS REPRESENTATIVE

JOINT NO. 4



ASSUME CIRCULAR PLATE FOR COLLAR



FOR COLLAR

$$* \ \max y = \frac{\alpha W C^2}{E t^3}$$

$$C/b = \frac{3.919}{2.896} = 1.35$$

$$\alpha = .412$$

$$k_c = \frac{W}{y} = \frac{E t^3}{\alpha C^2} = \frac{22 \times 10^6 (.55)^3}{.412(3.919)^2}$$

$$k_c = 580000 \ LBS/IN$$

FOR 6 - 3/8" BOLTS

$$D = 0.375''$$

$$L = 1.170''$$

$$y = \frac{WL}{A_r E}$$

$$k_B = \frac{W}{y} = \frac{A_r E}{L} = \frac{(6 \times .785 \times .375^2)(22 \times 10^6)}{1.170}$$

$$K_B = 12.4 \times 10^6 \ \frac{LBS}{IN}$$

* REF. - FORMULAS FOR STRESS AND STRAIN - ROARK

CHECK EFFECTS OF DIFFERENT COEFFICIENTS OF THERMAL EXPANSION

JOINT NO. 7

ELEMENT	MAT'L	TEMP. (°F)	β (IN/IN-°F)
STUD	INCONEL X	1298	8.3×10^{-6}
FLANGE	SS, TYPE 316	1298	11.1×10^{-6}
COLLAR	INCONEL X	1298	8.3×10^{-6}

$$\Delta\delta = \delta_{SS} - \delta_{INCO} = L(\beta_{SS} - \beta_{INCO})(\Delta T)$$
$$= .37(11.1 - 8.3)(10^{-6})(1230) = .001275 \text{ IN.}$$

THIS DIFFERENTIAL FREE THERMAL DEFLECTION IS SUCH AS TO INCREASE THE BOLT LOAD & TIGHTEN THE CONNECTION.

THE BOLT ELASTIC STRAIN WOULD BE INCREASED BY:

$$\frac{.58}{(.58 + 12.4)} \times .001275 = .0000569 \text{ IN.} = y \qquad \text{(REF. P. 15)}$$

THE BOLT IS STRESSED TO IN TIGHTENING. (REF. P. 19) $\frac{13100}{1.27} = 10200$ PSI (DIRECT TENSILE STRESS)

THEN:

$$\Delta\sigma = \frac{Ey}{L} = \frac{22 \times 10^6 (56.9 \times 10^{-6})}{1.170} = 1070 \text{ PSI}$$

WHICH IS NEGLIGIBLE SINCE THE RATIO OF

$$\frac{W}{W_{m_1}} = \frac{5100}{2320} = 2.2 \qquad \text{(REF. P. 19)}$$

CHECK THE EFFECTS OF RELAXATION IN 10000 HRS.

FOR 0.1% RELAXATION IN 10000 HRS IN THE BOLT:

$\delta = .001\,(1.17) = .00117''$

$$\frac{1}{K_{TOTAL}} = \frac{1}{K_B} + \frac{1}{K_C} = \frac{1}{12.4\times10^6} + \frac{1}{.58\times10^6} = 10^{-6}\left(\frac{.58+12.4}{12.4\times.58}\right)$$

$$= 10^{-6}\frac{(12.98)}{(12.4)(.58)}$$

$K_{TOT} = 554000$ LBS/IN

$\Delta W = (.00117)(554000) = 650$ LBS (CHANGE IN TIGHTENING LOAD)

WHICH IS NEGLIGIBLE (REF. P.19)

COMBINED BOLT STRESSES

USING MAXIMUM STRAIN THEORY BY SAINT-VENANT

$$S = 0.5\left[(1-\epsilon)\sigma + (1+\epsilon)(\sigma^2 + 4\tau^2)^{1/2}\right]$$

$$\epsilon = 0.3$$

$$S = 0.5\left[.7\sigma + 1.3(\sigma^2+4\tau^2)^{1/2}\right] = \underline{.35\sigma + 0.65(\sigma^2+4\tau^2)^{1/2}}$$

$$\sigma = \frac{P}{.785 D_M^2} = \frac{1.28P}{D_M^2} \; ; \; \tau = \frac{16T}{\pi D_M^3} = 5.08\frac{T}{D_M^3}$$

SINCE $T = 0.2\,DP$ (APPROXIMATELY 50% IS TRANSMITTED)

& FOR A .375-24 UNF-3A THREAD $D_M = .324''$; $D = 1.16\,D_M$

FOR A .250-28 UNF-3A THREAD $D_M = .206''$; $D = 1.21\,D_M$

USING $D = 1.21\,D_M$

$$T_{TRANSM.} = 0.1(1.21 D_M)P = \underline{0.121\,D_M P}$$

$$\tau = \frac{5.08(0.121\,D_M P)}{D_M^3} = \underline{\frac{0.615P}{D_M^2} = \tau}$$

$$\tau = \frac{.615}{1.28}\sigma = 0.48\,\sigma \quad (\text{SAY } 0.5\,\sigma)$$

$$S = 0.35\sigma + .65\left[\sigma^2 + 4(.5\sigma)^2\right]^{1/2}$$

$$S = 0.35\sigma + .65\left[\sigma^2 + \sigma^2\right]^{1/2} = (.35 + .65\sqrt{2})\sigma = 1.27\sigma$$

					FLANGE LOADS (OPER. COND.)		
JOINT NO.	TIGHTENING FORCE (LBS)	TIGHTENING COMBINED BOLT STRESS (PSI)	TOTAL PRESS. END FORCE (LBS)	MINIMUM LOAD REQ'D. TO MAINTAIN SEAL (LBS)	(LBS)	(LBS)	(LBS)
	W	$S = \frac{1.27W}{6\,(.785D^2_{MIN})}$	$H = .785G^2P$	Wm_1	$H_D = .785B^2P$	$H_G = W_{m1} - H$	$H_T = H - H_D$
1	1,950	12,400	246	720	129	474	117
2	2,250	14,300	8	720	5	712	3
3	10,800	27,800	1,010	2,160	544	1,150	466
4	5,100	13,100	115	2,320	74	2,205	41
5	7,500	19,300	168	2,320	108	2,152	60
6	8,700	22,400	111	4,080	72	3,969	39
7	8,700	22,400	139	4,560	100	4,421	39
8	7,500	19,300	168	2,320	108	2,152	60
9	1,500	3,860	18	480	11	462	7

NOTES:

1. Reference - Pages 6, 8, 9, 11, 12, and 18
2. Reference - A.S.M.E. Unfired Pressure Vessel Code-1962

JOINT NO.	FLANGE MOMENTS (OPER. COND.) (IN-LBS)	(IN-LBS)	(IN-LBS)	TOTAL MOMENT (IN-LBS)	FLANGE MOMENT (BOLT-UP COND.) (IN-LBS)	MAXIMUM MOMENT (IN-LBS)	MOMENT CORRECTED FOR BOLT SPACING (IN-LBS)
	$M_D = H_D \times h_D$	$M_G = H_G \times h_g$	$M_T = H_T \times h_T$	$M_D = M_o + M_G + M_T$	$M_a = Wh_G$	$*M_{MAX} = M_o$ or MAX $\frac{f_{FO}}{f_{FA}}$	$M = \frac{M_{MAX}}{B}$
1	79.8	232	64.9	376.7	950	890	1,310
2	3.1	350	1.7	354.8	1,100	1,020	1,100
3	574.0	890	425.0	1889.0	8,350	5,120	3,280
4	74.7	1,708	36.5	1819.2	3,940	2,230	1,170
5	108.7	1,665	53.4	1827.1	5,800	5,420	2,850
6	98.8	3,770	45.3	3914.1	8,260	7,470	2,130
7	137.3	4,480	46.7	4664.0	8,830	7,980	1,935
8	108,7	1,660	53.4	1822.1	5,800	5,410	2,840
9	6.8	227	3.9	237.7	736	694	747

	IF STUD SPACING EXCEEDS 2d + t					MARGIN OF SAFETY	
JOINT NO.		(IN-LBS)				BOLT	*COLLAR
	C.F. = $\frac{\text{Bolt Spacing}}{t}$	$M = \frac{M_{MAX} \times C.F.}{B}$	K = A/B	Y	$f_T = MY/t^2$		
1	1.785	2,340	3.65	1.7	44,200	+3.83	+0.09
2	1.900	2,090	2.94	1.9	44,600	+3.20	+0.08
3	1.827	6,000	2.99	1.9	37,600	+0.36	+0.01
4	1.887	2,210	2.58	2.4	17,500	+1.67	+1.00
5	1.887	5,380	2.58	2.4	42,700	+2.11	+0.13
6	2.280	4,870	2.02	3.0	40,700	+1.57	+0.15
7	2.390	4,620	1.87	3.3	42,300	+1.57	+0.10
8	1.887	5,370	2.58	2.4	42,700	+2.11	+0.13
9	1.470	1,097	2.93	1.9	8,300	+14.30	+6.10

I. Margin of Safety denotes the margin above the required Factor of Safety.

REFERENCES

1. Process Equipment Design - Brown and Young

2. Code for Pressure Piping, ASA B31.1 - 1955

3. ASME Unfired Pressure Vessel Code - 1962

4. TM 340:64-1-185, Piping Load and Stress Analysis - MLA, SL-1

5. ASME Handbook - Metals Engineering Design - O. J. Horger

6. Formulas for Stress and Strain - Roark

TM 340:64-1-187 and

TM 340:64-1-187 (Supplement A)

COMPONENT PIPING CONNECTION LOADS - MLA, SL-1

COMPONENT PIPING CONNECTION LOADS - PCS-1, PCS-2 (SUPPLEMENT)

Table I, titled "Summary - PCS-2 Component Piping Loads (Revised)," of Supplement A (dated 17 December 1964, is applicable to the LeRC turbine alternator assembly. The original technical memo, dated 5 February 1964, is included for information only.

10-047-009 (REV. 6/63)

DIVISION SNAP-8
TM 340:64-1-187
DATE 5 February 1964
W.O. 0743-02-2000

TECHNICAL MEMORANDUM

AUTHOR(S): A. Levitsky

TITLE: COMPONENT PIPING CONNECTION LOADS-MLA, SL-1

ABSTRACT

This TM designates the piping connection design load data for the MLA components. This data has been checked by the cognizant component design groups and was found to be acceptable.

APPROVED:

DEPARTMENT HEAD P. I. Wood

P. I. Wood

I. INTRODUCTION

The thermal expansion forces and moments that piping may exert on high-speed rotating machinery need to be carefully controlled in order to avoid malfunction resulting from misalignment, rubbing, binding, or excessive wear. This may be accomplished by proper positioning of equipment, intermediate restraints, coldspring, expansion joints, or flexible piping. Where the geometry allows and the pipe diameter is small, as was the case for the Mercury PMA lines and the turbine inlet line, it is easiest to design the flexibility into the pipe itself through proper piping layout. The turbine outlet, however, being a short run and of larger size (3.63 in. diameter) required an expansion joint for maintaining loads at an acceptable level.

A somewhat similar problem exists at a vessel piping connection, particularly when the radius to wall thickness ratio is high. High localized bending and membrane stresses may be introduced, which, if not controlled, may lead to excessive distortion or even failure. The solution of this problem lies in a combination of controlling the flexibility of the piping via piping bends or expansion joints, and reinforcing the vessel locally at the piping connection, as required.

II. CONCLUSIONS AND RECOMMENDATIONS

The SL-1 Mercury Loop Assembly piping design and the resulting loads at the component piping connections are acceptable for the ground test system. The prototype system, however, will have to withstand high static acceleration as well as shock and vibration loads. In some cases, the requirements for thermal expansion design, i.e., increased pipe line flexibility, may be the reverse of that required for adequate vibration design. Expansion joints, with their inherent reliability problems, will be utilized only where absolutely necessary. In addition, the piping length and wall thickness will have to be kept to a minimum because of limited space and weight requirements. The adequate solution of this problem will involve:

a. Reinforcing component connections where possible, so that the limiting item is the stress in the line rather than the local stress at the component piping connection.

b. Careful design, which should utilize where necessary, adequate partial restraints and efficient component placement.

c. Adequate stress and dynamic analysis.

III. SYMBOLS

Fx - Force in the x direction (pounds)

Fy - Force in the y direction (pounds)

Fz - Force in the z direction (pounds)

Mx - Moment about the x axis (inch-pounds)

My - Moment about the y axis (inch-pounds)

Mz - Moment about the z axis (inch-pounds)

C - Cold spring factor varying from 0 for no cold spring to 1 for 100% cold spring

Sh - Allowable stress at operating temperature (psi)

S_E - Maximum computed equivalent expansion stress $\sqrt{\sigma_b^2 + 4\tau^2}$ (psi)

Ec - Modulus of elasticity in the cold condition (psi)

Rr - Range of reactions corresponding to the full expansion range based on Ec (pounds)

Rc - The maximum estimated reaction occurring in the cold condition (pounds)

Rh - The maximum estimated reaction occurring in the hot conditions (pounds)

σ_b - Resultant longitudinel bending stress (psi)

τ - Resultant torsional shear stress (psi)

IV. RESULTS AND DISCUSSION

For simplification in analysis, the ends of all the piping systems analyzed were considered fixed at the component connections. This results in the maximum possible reactions, as localized bending moments and axial loads will cause deflections and/or rotations thus reducing the piping reactions. This is indicative of the actual end conditions which are somewhere in between fixed-end and hinged-end, rather than fixed-end. This simplification, however, is not excessively conservative since in many cases we are dealing with sensitive rotating components whose geometry involves complex and discontinuous contours which are not amenable to a reliable stress and deflection analysis.

The thermal expansion analyses that were performed on all of the piping assemblies were based on the "hot" Modulus of Elasticity, and the assumption of no cold spring or initial fabrication stress. The resultant reactions at the component connections are the maximum possible reactions during the operating condition. They are realistic since the Mercury Loop piping in SL-1 will be cut, fit, and welded to the flanges on assembly, resulting in negligible fabrication stresses. The maximum hot reaction will generally exist only during the initial start-up cycle, and will subsequently drop off due to yielding and creep in the pipe line. Loads and stresses are thus shifted so that they reappear in the cold condition with altered magnitude and with opposite sign. The Piping Code provides the following rules on the subject:

$$Rh = (1 - 2/3C)\ Eh/Ec\ \ Rr$$

$$Rc = CRr \quad , \text{ or}$$

$$Rc = (1 - Sh/S_E \times Ec/Eh)\ Rr$$

The value of Rc is taken as the greater of the two values indicated above, with the further condition that:

$$Sh/S_E \times Ec/Eh \text{ is less than } 1$$

For temperatures in the creep range, the hot reaction will eventually be lowered to a value equal approximately to $Sh/S_E\ Rr$.

The individual hot and cold reactions as indicated above are the significant values when judging their effects on sensitive rotating equipment. For piping connections on vessels, however, the reaction range rather than the individual hot or cold reaction is the significant factor.

Tables I through V contain the piping load data applicable to the SL-1 Mercury Loop Assembly components.

REFERENCES

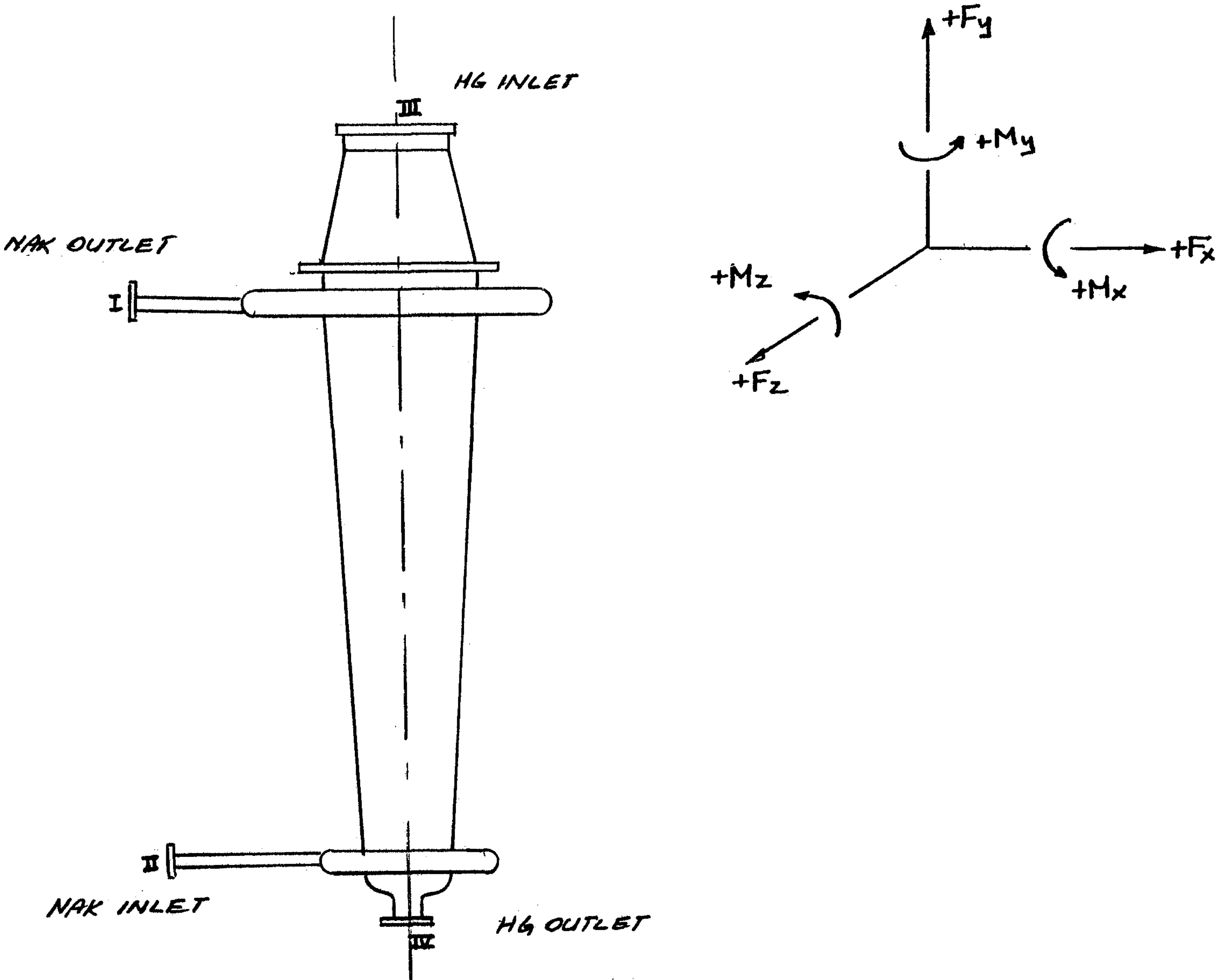
1. Code for Pressure Piping, ASA B31:1-1955

2. Design of Piping Systems - The M. W. Kellogg Company

3. TM 340:64-1-185, Piping Load and Stress Analysis - MLA, SL-1

TABLE I

CONDENSER PIPING CONNECTION LOADS, SL-1

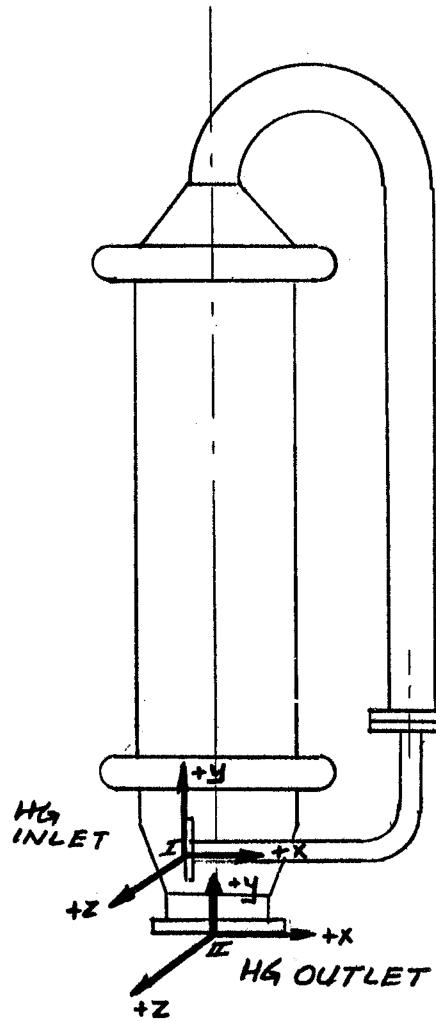


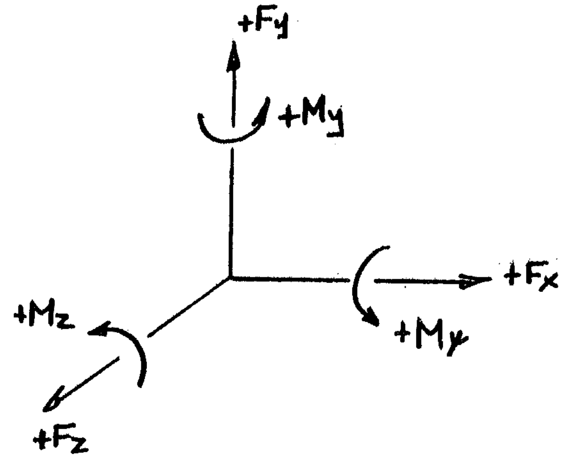
		EXPANSION JOINT OR PIPING SPRING FORCES					
NO.	PRESSURE THRUST (LBS)	Fx (LBS)	Fy (LBS)	Fz (LBS)	Mx (IN-LBS)	My (IN-LBS)	Mz (IN-LBS)
I	150	20	10	0	0	0	- 75
II	200	20	35	0	0	0	-175
III	0	0	0	50	-450	0	0
IV	0	1.6	8.5	- 2.7	- 48.2	54.6	122.5

NOTE:
1. Pressure thrusts result from the use of unrestrained expansion joints.
2. Pressure thrusts and expansion joint spring forces act simultaneously.

TABLE II

TURBINE SIMULATOR MERCURY PIPING CONNECTION LOADS, SL-1





FLANGE LOADINGS - ON TURBINE SIMULATOR Hg CONNECTIONS

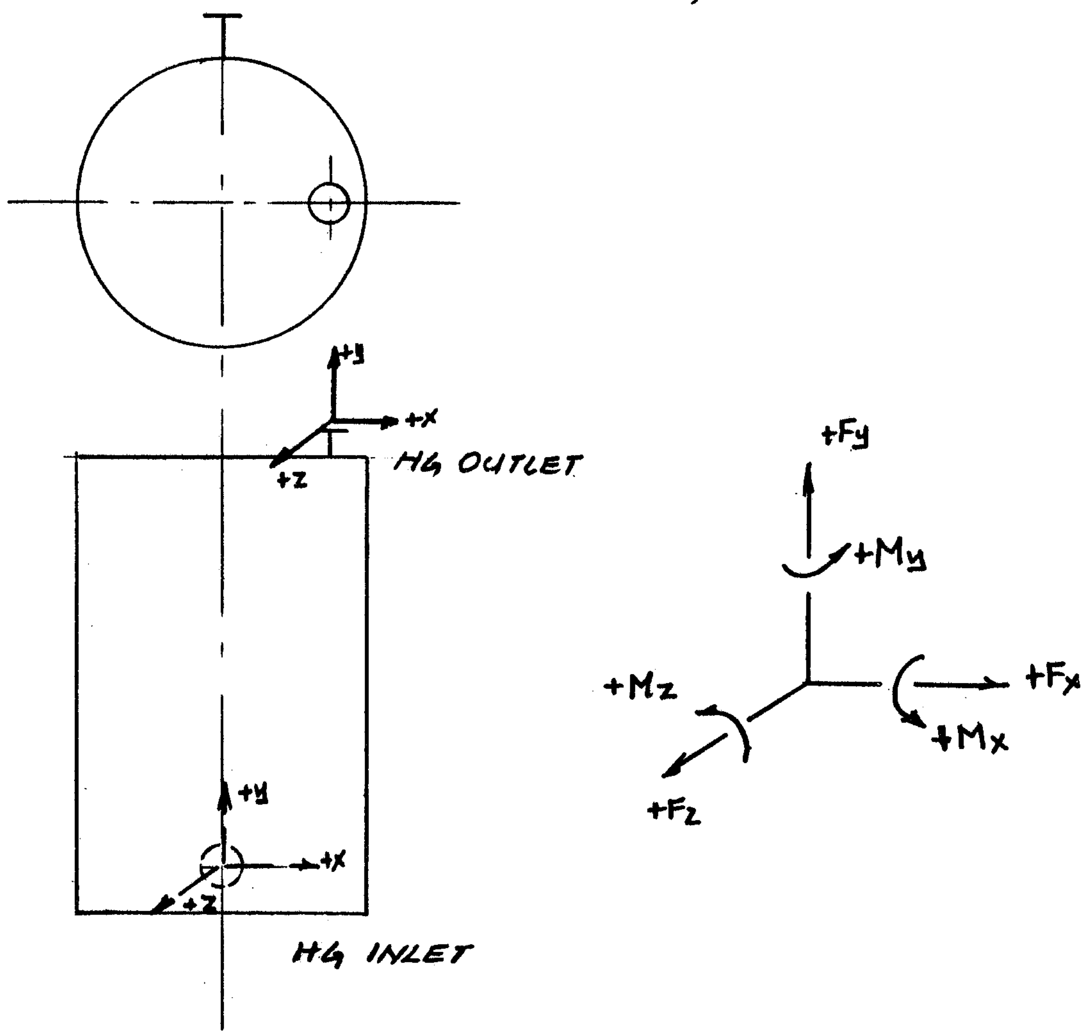
	Hg INLET - I		Hg OUTLET - II	
	DUE TO THERMAL EXPANSION	GRAVITY LOADING (1G)	DUE TO THERMAL EXPANSION	GRAVITY LOADING (1G)
Fx (lbs)	- 24.2	- 0.2	- 50.0	Negligible
Fy (lbs)	37.4	- 21.6	50.0	Negligible
Fz (lbs)	60.4	- 0.3	0	Negligible
Mx (in-lbs)	1060.0	-338.0	0	Negligible
My (in-lbs)	777.0	9.4	0	Negligible
Mz (in-lbs)	- 75.5	195.0	-350.0	Negligible

NOTE:

1. All loads occur simultaneously.

TABLE III

BOILER PIPING CONNECTION LOADS, SL-1



FLANGE LOADS ON BOILER PIPING CONNECTIONS

	MERCURY OUTLET		MERCURY INLET	
	DUE TO THERMAL EXPANSION	DUE TO GRAVITY LOADING (1G)	DUE TO THERMAL EXPANSION	DUE TO GRAVITY LOADING (1G)
Fx (lbs)	24.2	0.17	2.5	0.5
Fy (lbs)	- 37.4	- 24.1	3.4	- 8.4
Fz (lbs)	- 60.4	0.3	- 3.3	0.1
Mx (in-lbs)	- 506.0	-307.0	21.3	-56.0
My (in-lbs)	-1185.0	2.6	33.6	1.7
Mz (in-lbs)	560.0	176.0	19.9	-41.3

TABLE III (CONTINUED)

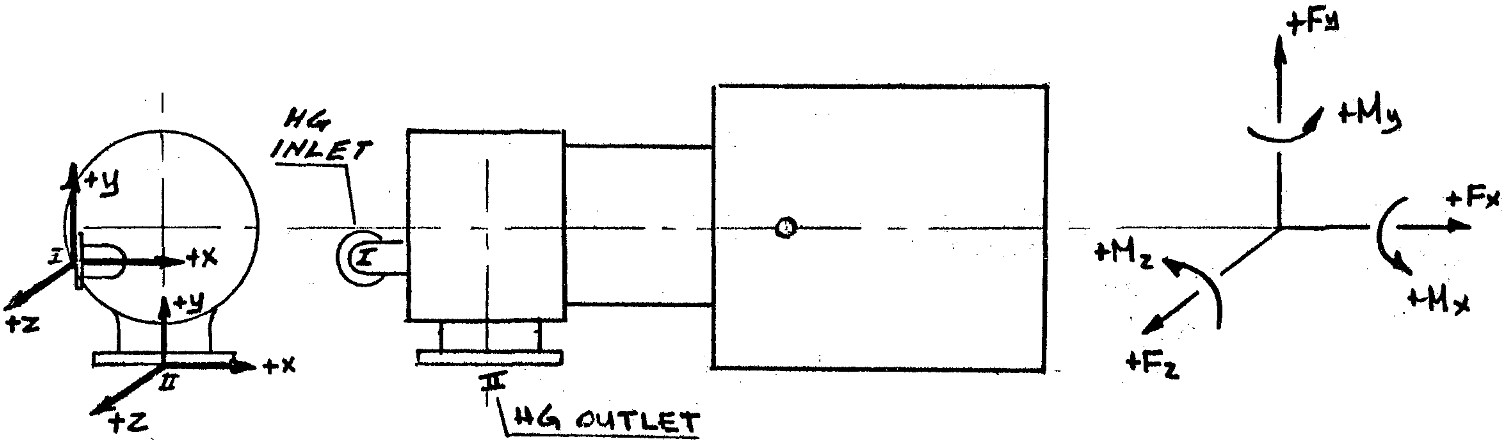
ATTACHMENT	BOILER NaK PIPING CONNECTIONS - THERMAL EXPANSION LOADS			
	AXIAL LOAD (LBS)	TRANSVERSE LOAD (LBS)	TORQUE (IN-LBS)	BENDING MOMENT (IN-LBS)
NaK Inlet	±50	±50	±50	±50
NaK Outlet	±50	±50	±50	±50

NOTE:

1. Loads on NaK Piping Connections are by specification control.
2. Gravity loads on NaK Piping Connections are negligible.
3. Loads on all Piping Connections occur simultaneously.

TABLE IV

TURBINE MERCURY PIPING CONNECTION LOADS, SL-1



FLANGE LOADINGS - ON TURBINE

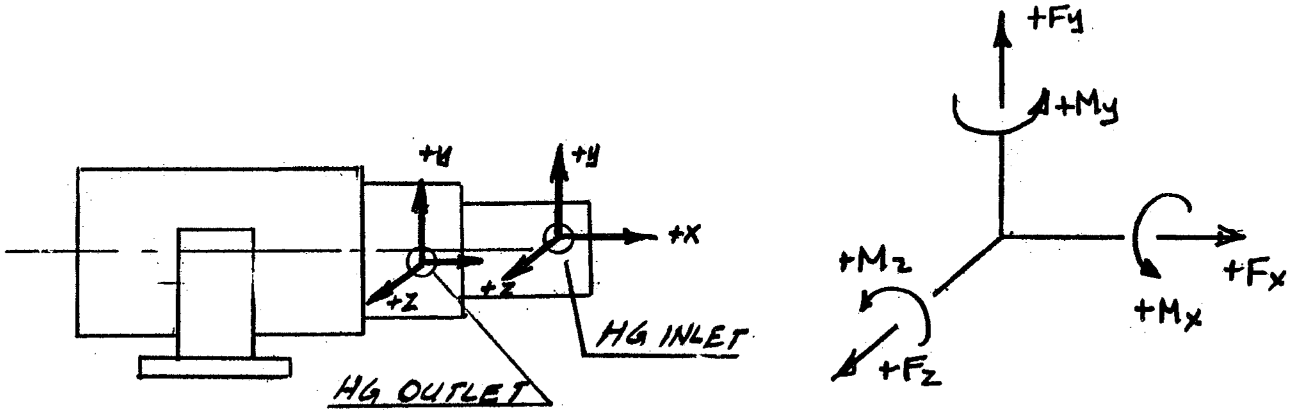
	I		II	
	DUE TO THERMAL EXPANSION	GRAVITY LOADING (1G)	DUE TO THERMAL EXPANSION	GRAVITY LOADING (1G)
Fx (lbs)	- 17.3	- 0.2	0	Negligible
Fy (lbs)	+ 15.6	- 21.6	+ 10	Negligible
Fz (lbs)	+ 53.1	- 0.2	- 50	Negligible
Mx (in-lbs)	+434.0	-338.0	+350	Negligible
My (in-lbs)	+560.0	+ 9.4	0	Negligible
Mz (in-lbs)	- 40.7	+195.0	0	Negligible

NOTES:

1. All Loads Occur Simultaneously.

TABLE V

MERCURY PMA PIPING CONNECTION LOADS, SL-1



PIPING THERMAL EXPANSION LOADS ON MERCURY CONNECTIONS
(AT FLANGES)

	Hg INLET (I)	Hg OUTLET (II)
Fx (lbs)	- 15.6	- 2.1
Fy (lbs)	- 2.2	- 0.8
Fz (lbs)	- 5.5	- 5.2
Mx (in-lbs)	- 30.4	9.1
My (in-lbs)	-198.0	29.4
Mz (in-lbs)	- 14.1	- 8.5

10-047-009 (REV. 6/63)

DIVISION SNAP-8
TM 340:64-1-187 (SUPPLEMENT "A")
DATE 17 December 1964
W.O. 0743-02-2000

TECHNICAL MEMORANDUM

AUTHOR(S): A. Levitsky

TITLE: COMPONENT PIPING CONNECTION LOADS - PCS-1, PCS-2 (SUPPLEMENT)

ABSTRACT

This TM designates the piping connection design load data for the PCS-1 and PCS-2 components. This data has been checked by the cognizant component design groups and was found to be acceptable.

NOTE: This document is a supplement to TM 340:64-1-187 dated 5 February 1964

APPROVED:
DEPARTMENT HEAD P. I. Wood
P. I. Wood

AEROJET-GENERAL CORPORATION

COPY NO. 21
PAGES:

MEMORANDUM

TO:	Distribution	2 November 1964 AL:ljm
FROM:	A. Levitsky	340:64:0101

SUBJECT: Component Piping Loads, PCS-2 (Revised)

DISTRIBUTION: E. G. Brittain, C. P. Colker, E. Eber, H. B. Ellis, L. A. Geer, R. Hill, W. M. Kauffman, A. H. Kreeger, R. L. Lessley, R. W. Marshall, J. R. Pope, H. D. Tabakman, P. I. Wood, File

ENCLOSURE: (1) Summary - PCS-2 Component Piping Loads (Revised)

REFERENCE: (a) Memo No. 340-64-0097, A. Levitsky to Distribution, Subject: Component Piping Loads, PCS-2

The data enclosed with this memo covers the revised forces and moments on the PCS-2 components due to connecting piping. These loads have been checked by the cognizant personnel and are considered acceptable.

A. Levitsky

A. Levitsky
System Design, Dept. 340
SNAP-8 Division

Approved by:

L A Geer

L. A. Geer, Supervisor
System Design, Dept. 340
SNAP-8 Division

Enclosure (1)

TABLF I

SUMMARY - PCS-2 COMPONENT PIPING LOADS (REVISED)

NO.	COMPONENT	DESCRIPTION	AXIAL FORCE (pounds)		RADIAL FORCE (Pounds)		BENDING MOMENT (Foot-Pounds)		TORSION (Foot-Pounds)	
			Thermal	Gravity	Thermal	Gravity	Thermal	Gravity	Thermal	Gravity
1	HRL PMA (C. P. Colker)	NaK Inlet	24	--	38	3	55	2	--	8
		NaK Outlet	1	--	25	18	30	8	--	2
2	Primary PMA (C. P. Colker)	NaK Inlet (8)(9)(10)	11	--	15	28	34	27	46	--
		NaK Outlet (9)	8	1	31	17	30	15	45	1
3	Condenser (A. H. Kreeger)	NaK Inlet	51	--	19	--	48	--	12	--
		NaK Outlet	4	--	40	--	8	--	26	--
		Hg Inlet	10	--	50	--	38	--	--	--
		Hg Outlet	9	--	4	--	11	--	5	--
4a	Boiler (Operating) (A. H. Kreeger)	NaK Inlet (10)(8)	3	--	23	27	43	18	31	18
		NaK Outlet (9)	45	60	18	--	41	--	6	--
		Hg Inlet	4	1	5	9	4	5	2	4
		Hg Outlet	23	16	12	--	51	16	14	--
4b	Boiler (Pre-Heat) (A. H. Kreeger)	Hg Outlet	6	16	58	--	28	16	75	--
5	Parasitic Load Resistor (E. G. Brittain)	NaK Inlet (9)	23	1	22	17	39	18	24	3
		NaK Outlet (9)(8)	21	--	48	24	18	6	63	16
6	Auxiliary Heat Exchanger (A. H. Kreeger)	3/4" OD NaK Inlet	1	--	18	--	14	--	18	--
		3/4" OD NaK Outlet	8	--	18	--	13	--	13	--
		2.0" NaK Inlet (9)	69	--	40	--	82	--	15	--
		2.0" NaK Outlet (9)	35	--	41	--	14	--	10	--

NO.	COMPONENT	DESCRIPTION	AXIAL FORCE (Pounds)		RADIAL FORCE (Pounds)		BENDING MOMENT (Foot-Pounds)		TORSION (Foot-Pounds)	
			Thermal	Gravity	Thermal	Gravity	Thermal	Gravity	Thermal	Gravity
7*	SV-1 Temperature Control Valve (R. L. Lessley)	2" OD NaK Inlet	40	--	8	--	27	--	5	--
		2" OD NaK Outlet	53	--	7	--	9	--	5	--
		3/4" OD NaK Outlet (8)	1	--	11	--	7	--	6	--
8	FCV-8 (R. L. Lessley)	NaK Inlet (8)	11	--	3	--	13	--	1	--
		NaK Outlet	1	--	18	--	5	--	2	--
9	FCV-4 (R. L. Lessley)	NaK Inlet	49	--	24	16	85	23	--	8
		NaK Outlet	16	--	52	--	45	--	21	--
10 a+	Turbine (Pre-Heat)	Hg Inlet	52	--	28	9	88	1	13	3
10 b	Turbine (Operating) (G.Oiye)	Hg Inlet	3	--	25	--	24	--	69	--
		Hg Outlet	10	--	50	--	38	--	0	--

NOTE: 1. Thermal and gravity loads occur simultaneously.

2. Where no loads are shown, loads may be considered negligible.

*3. Two valves here are coupled directly so that only three piping connections exist.

4. Forces and moments may be assumed to combine in such a manner as to result in the most critical combination.

+5. Pre-heat condition exists for less than 100 hours.

6. Hg PMA piping loads for PCS-2 identical to that of PCS-1 and may be found in TM 340:64-1-187.

7. Piping loads on L/C PMA are negligible

Addenda

8. These loads have been upgraded from data presented in the original memorandum, but are still considered to be within acceptable limits.

9. During startup these components will experience thermal expansion loads approximately 8% higher than indicated. This condition is still within acceptable limits.

10. Reference Table VII for complete breakdown of loads.

01-071-002

QUADRILLE WORK SHEET

AEROJET GENERAL

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

PAGE ____ OF ____ PAGES

DATE ____

WORK ORDER ____

SUBJECT ____ BY ____

TABLE VII

COMPONENT CONNECTION	M_x (FT-LBS)			M_y (FT-LBS)			M_z (FT-LBS)			F_x (LBS)			F_y (LBS)			F_z (LBS)		
	THERM	GRAV.	TOTAL	THERM.	GRAV.	TOTAL	THERM	GRAV	TOTAL	THERM	GRAV.	TOTAL	THERM	GRAV.	TOTAL	THERM	GRAV	TOTAL
+BOILER NAK INLET	31	17.3	48.3	42	-	42	-8	-17.5	25.5	-2.3	-	-2.3	7.4	27.4	34.8	20.9	-	20.9
+PRIMARY PMA NAK INLET	-45.1	* -	-45.1	-25	-	-25	-20	26.5	6.5	-11	-	-11	11.2	28	14	9.2	-	9.2

BOILER NAK INLET

$$M_{B_{TOT}} = \sqrt{42^2 + 25.5^2} = \sqrt{1760 + 650} = \sqrt{2410} = 49 \text{ FT-LBS} = \sqrt{M_{y_{TOT}}^2 + M_{z_{TOT}}^2}$$

$$M_{T_{TOT}} = M_{x_{TOT}} = 48.3 \text{ FT-LBS}$$

PRIMARY PMA NAK INLET

$$M_{B_{TOT}} = \sqrt{M_{y_{TOT}}^2 + M_{TOT}} = \sqrt{25^2 + 6.5^2} = \sqrt{625 + 42} = \sqrt{667} = 26 \text{ FT-LBS}$$

$$M_{T_{TOT}} = M_{x_{TOT}} = 45.1 \text{ FT-LBS}$$

NOTES:

*1. THIS LOAD MADE APPROXIMATLY EQUAL TO ZERO BY ADJUSTING SPRING LOADS.

+2. REFERENCE TM 340:64-1-185, PAGES 94, 104, 183, 189.

MEMORANDUM

TO: R. S. Foley ✓

12 September 1964
AL:ljm
340-64-0102

FROM: A. Levitsky

SUBJECT: TAA Trunnion Design and Analysis, PCS-1

DISTRIBUTION: C. G. Boone, E. Eber, L. A. Geer, P. I. Wood, File

ENCLOSURE: (1) TAA Trunnion Mount Design and Analysis, PCS-1

Enclosed please find the design and stress analysis for the TAA Trunnion Support for PCS-1.

A. Levitsky

A. Levitsky
System Design Section
SNAP-8 Division

Approved by:

L A Geer

L. A. Geer, Supervisor
System Design Section
SNAP-8 Division

TAA TRUNNION MOUNT DESIGN AND ANALYSIS, PCS-1

The ground test turbine-alternator trunnion mount is designed to provide support for the TAA, while allowing it to rotate in response to the thermal expansion between the TAA support and the upper condenser mount. Catalog item Bendix "Flexural Pivots" were used as they insure rotational freedom even if the mating surfaces between the trunnion and the pin "stick." This becomes a more critical portion of the design for the prototype unit, since rolling surfaces will tend to cold-weld in a high vacuum.

A secondary objective is to provide easy assembly while maintaining low fabrication costs. Toward this aim, the pivot housing is split so that the TAA (with pivot) can be easily lowered into position. Tolerances in the pivot axis direction are taken up by shimming between the pivot end and housing, while tolerances in the turbine axis direction are accommodated by making the diameter of the mating holes between the housing and the mount greater than that of the connecting bolts. Vertical tolerances are taken up by shimming between the TAA mount and the pivot housing. A conical washer is used between the pivot shim and the end of the pivot to allow for thermal expansion in the pivot axis direction while always maintaining zero clearance.

The prototype support assembly will be designed to absorb the higher static and dynamic acceleration loads encountered in flight. It will include flexural pivots designed specifically for the application, as well as an efficient low weight support structure. Where required for thermal expansion, the design will incorporate flexible elements rather than sliding on rolling joints.

QUADRILLE WORK SHEET

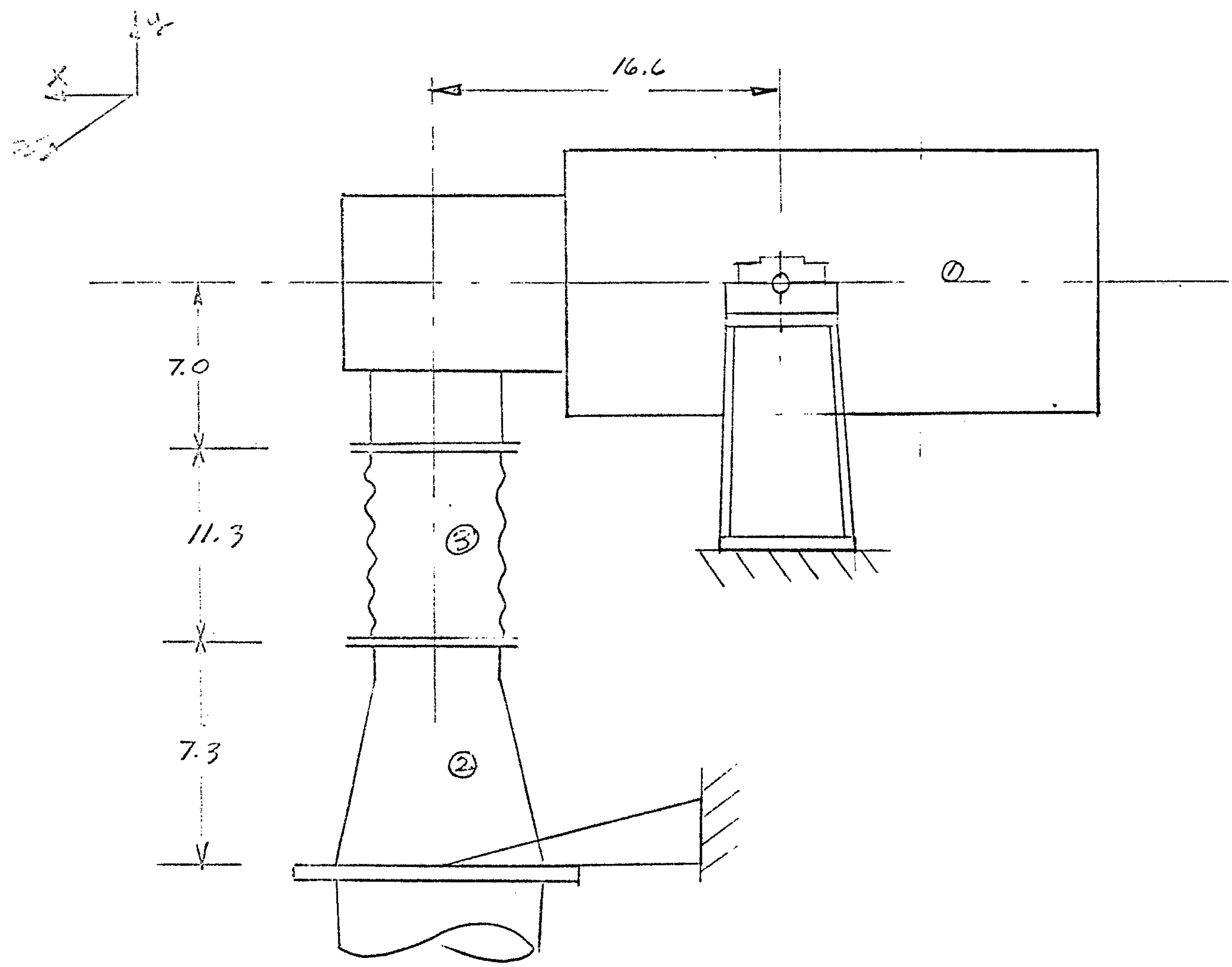
AEROJET GENERAL
AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

DATE ______

SUBJECT ______ BY ______ WORK ORDER ______

I GEOMETRY

A ARRANGEMENT (REF. DWG 092900)

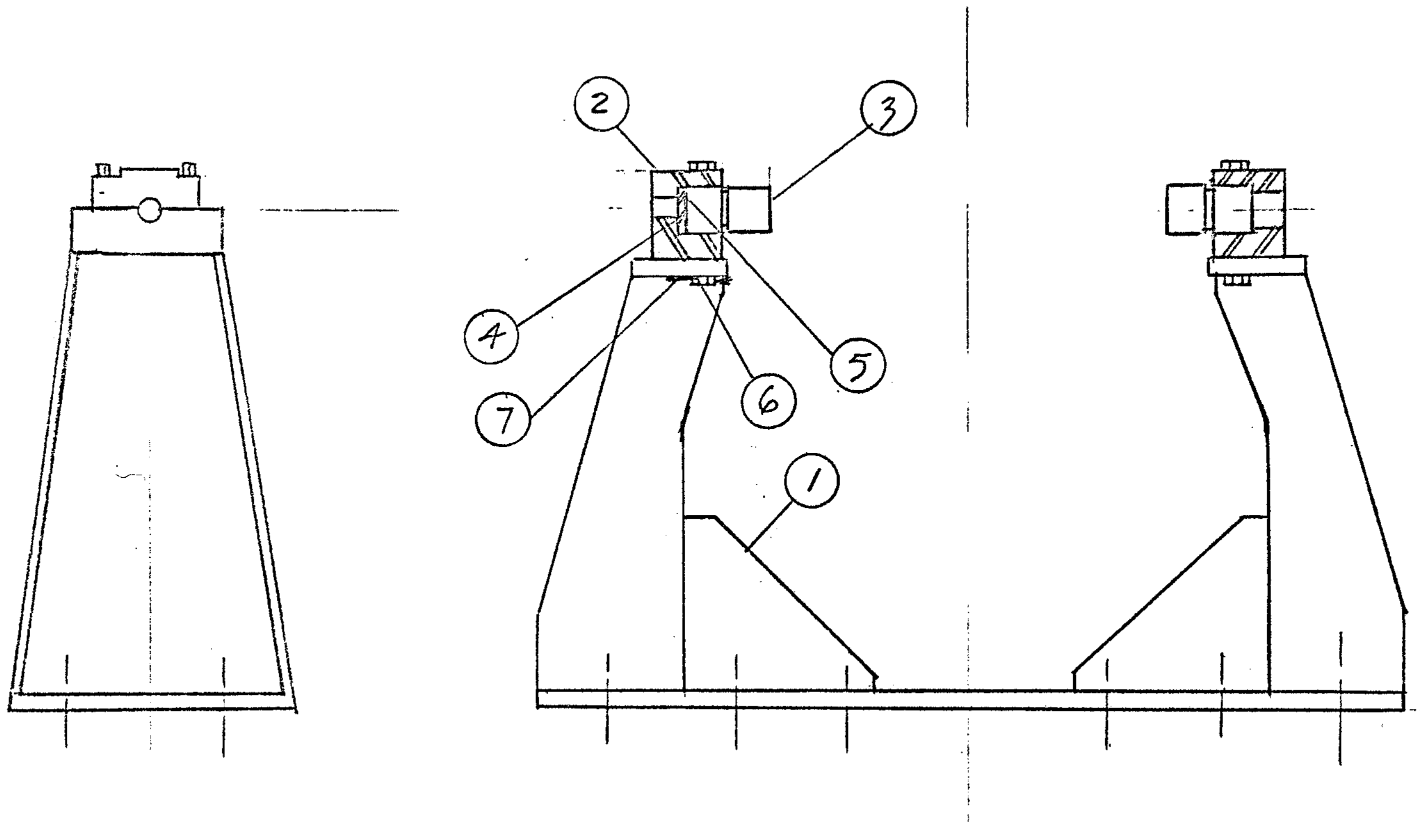


① TURBINE ALTERNATOR ASS'Y, REF DWG 09300

② CONDENSER ASS'Y - REF DWG 093043,

③ BELLOWS ASS'Y, TURBINE EXHAUST, REF DWG 091454

B TAA MOUNT DETAILS

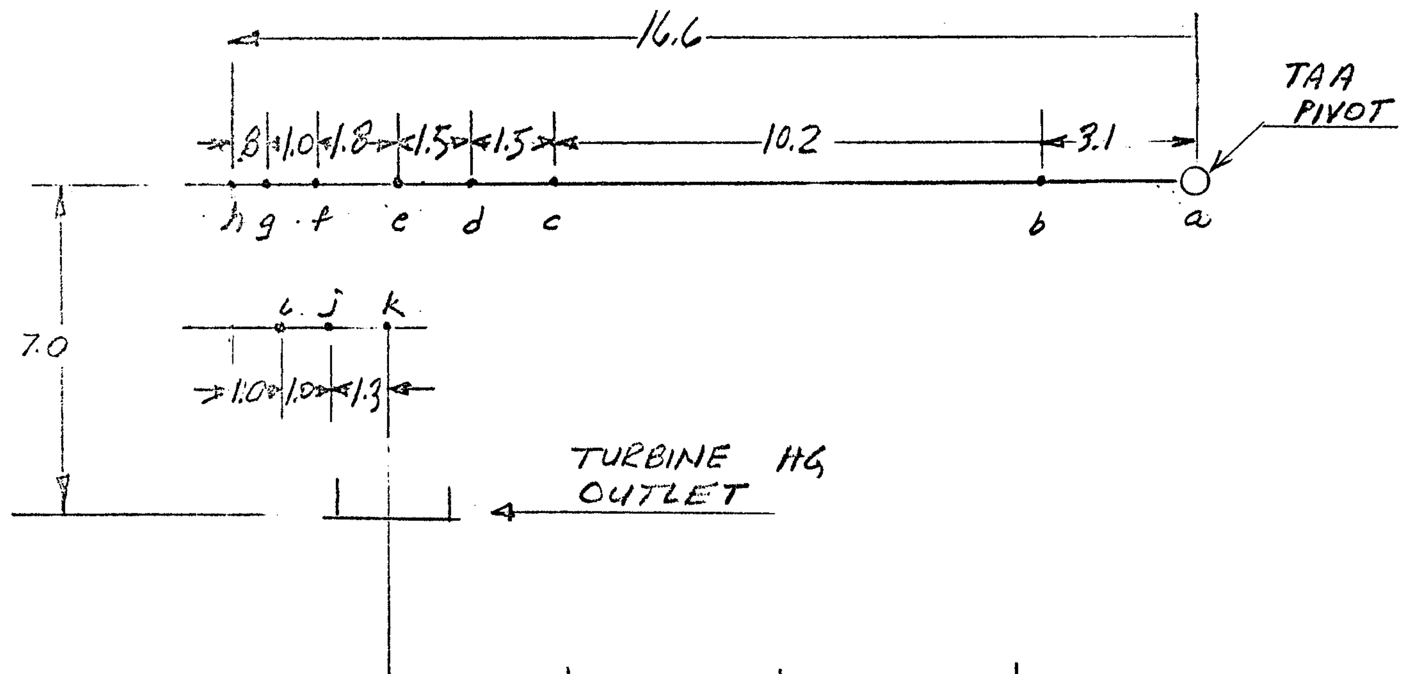


① TAA MOUNT - REF DWG 092592
② HOUSING - REF DWG 092583
③ PIVOT BODY - REF DWG 093089
④ SHIM - REF DWG 093000
⑤ CONICAL WASHER - REF DWG 093000
⑥ BOLT - REF DWG 093000
⑦ LOCKWIRE - REF DWG 093000

II ANALYSIS

A THERMAL EXPANSION

1. X - DIRECTION



ELEMENT	MATERIAL	AVG. TEMP-T (°F)	COEFF. OF EXP. - α IN/IN-°F	THERMAL EXPANSION - δ (IN)
ab	ARMCO IRON	285	6.5×10^{-6}	.00436
bc	9CR-1MO	295	6.0×10^{-6}	.01390
cd	↑	395	6.3×10^{-6}	.00370
de		516	6.57×10^{-6}	.00438
ef		645	6.81×10^{-6}	.00685
fg		787	6.95×10^{-6}	.00498
gh		913	7.02×10^{-6}	.00444
hi	↓	934	7.06×10^{-6}	-.00610
ij	9CR-1MO	877	7.00×10^{-6}	-.00564
jk	TYPE 410 SS	817	6.97×10^{-6}	-.00650

Σ .024 $= \delta_x$

$$\delta = \alpha L (T - 70)$$

QUADRILLE WORK SHEET

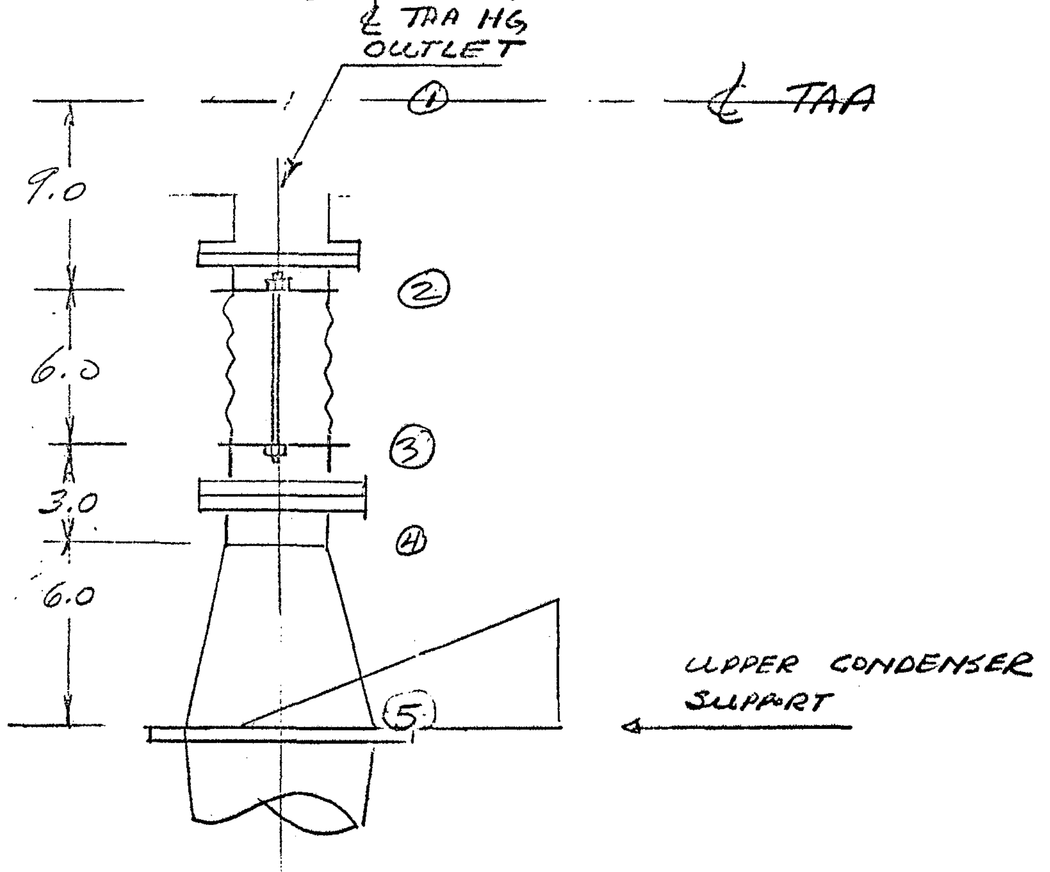
AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

PAGE 4 OF ____ PAGES

DATE ____

SUBJECT ____ BY ____ WORK ORDER ____

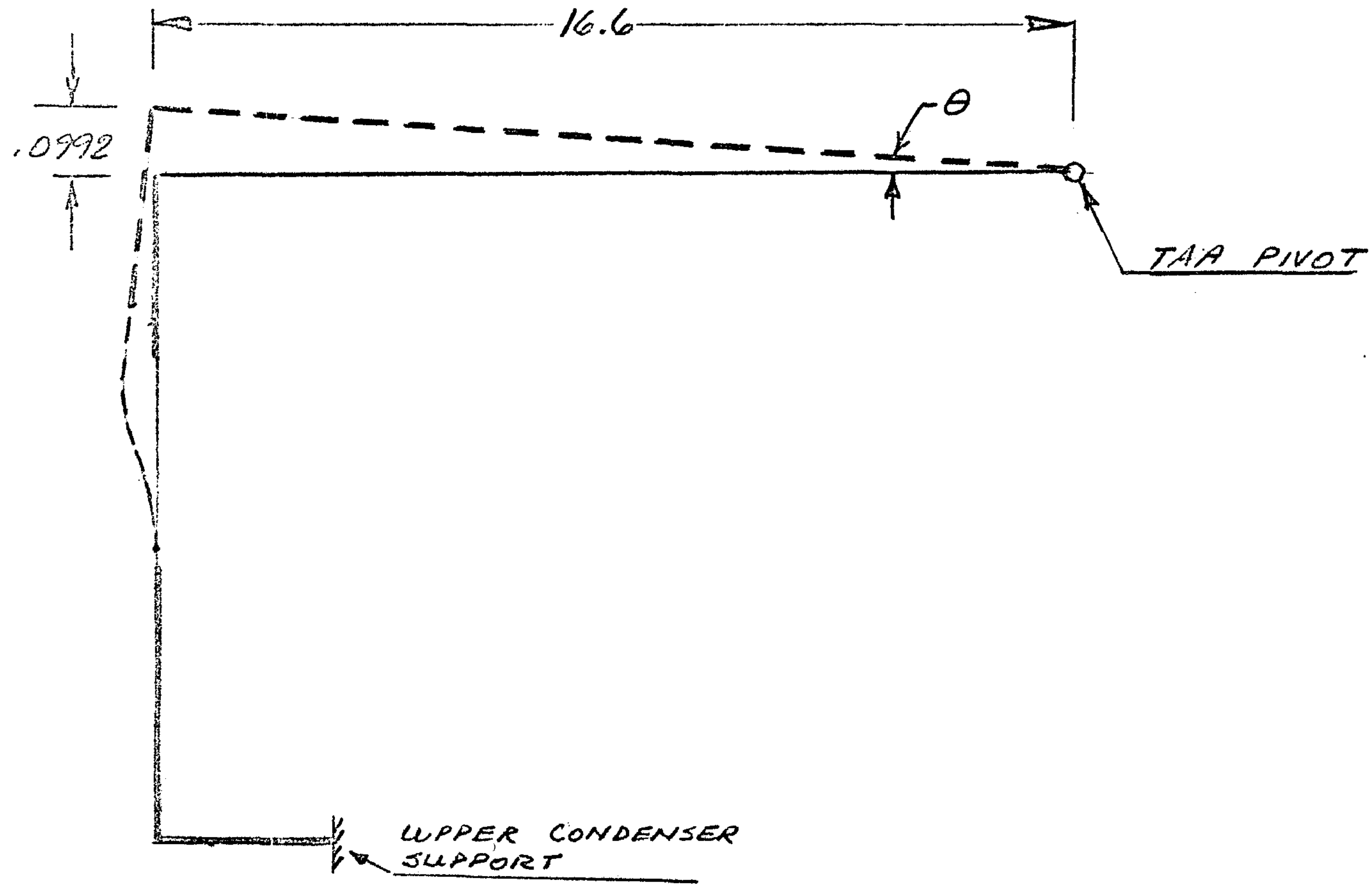
2. Y- DIRECTION
(ASSUME THAT TIE RODS HEAT UP TO OPERATING TEMP)



ELEMENT	MATERIAL	AVG TEMP, T (°F)	COEFF. OF EXP (IN/IN-°F), α	THERMAL EXPANSION (IN), δ
1-2	9CR-1MO	680	6.85×10^{-6}	.0375
2-3	AISI 4340	680	7.30×10^{-6}	.0265
3-4	9CR-1MO	680	6.85×10^{-6}	.0125
4-5	TYPE 410 SS	680	6.20×10^{-6}	.0227
			Σ	.0992 $= \delta_y$

$$\delta = \alpha (T - 70) L$$

DEFLECTION DIAGRAM (OPERATING CONDITION)



$\theta \simeq \frac{.0992}{16.6} \times 57.3 = 0.34°$ = ROTATION OF PIVOT

THE TAA PIVOT IS A BENDIX FLEXURAL PIVOT #5032-400, IT HAS A MAXIMUM PERMISSABLE ROTATION EQUAL TO 7.5° & A PURE RADIAL LOAD CAPACITY EQUAL TO 1280 LBS. SINCE THE TAA WEIGHT EQUALS ≈ 700 LBS, AND THE 2 PIVOTS SHARE THE LOAD;

$$\text{FACTOR OF SAFETY} = \frac{1280}{700/2} = 3.65$$ FOR GROUND TEST INSTALLATION

01-071-002

QUADRILLE WORK SHEET

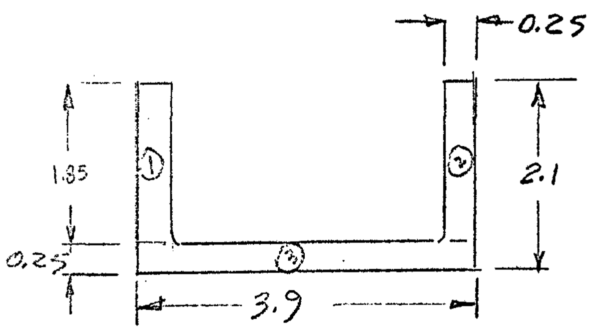
AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

DATE ____

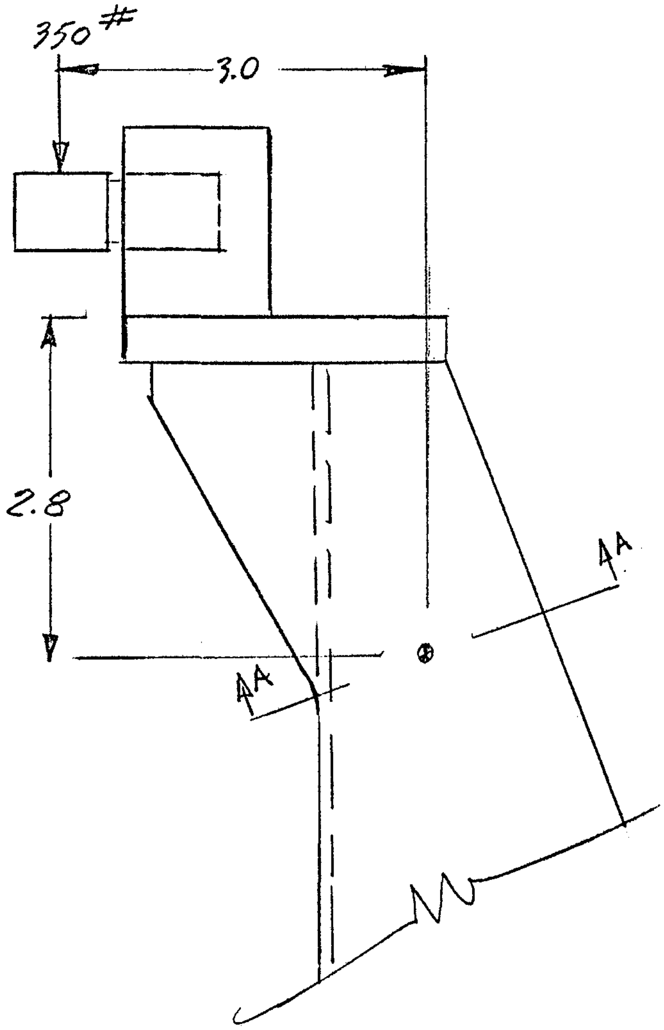
SUBJECT ____ BY ____ WORK ORDER ____

B. SUPPORT STRESS ANALYSIS

(BY INSPECTION, CRITICAL SECTION IS AT A-A.



SECTION AA



ELEM	A	y	y^2	Ay	Ay^2	I_o
1	.462	1.175	1.38	.542	.637	.132
2	.462	1.175	1.38	.542	.637	.132
3	.975	.125	.0156	.122	.015	–
	1.899			1.206	1.289	.264

$$\bar{y} = \frac{\Sigma Ay}{A} = \frac{1.206}{1.899} = 0.635 \checkmark$$

$$I = 1.289 - 1.899(.635)^2 + .264 = .788 \ IN^4$$

$$Z = \frac{I}{C} = \frac{.788}{1.465} = .538 \ IN^3$$

$M_A = 350(3) = 1050$ IN-LBS

$(\sigma_A)_{MAX} = \frac{M_A}{Z} = \frac{1050}{.538} = 1960$ PSI

MAT'L IS CARBON STEEL PLATE, TYPE 1020
WITH $\begin{cases} F_{TY} = 36000 \text{ PSI} \\ F_{TU} = 55000 \text{ PSI} \end{cases}$ (REF MIL-HDBK-5)

YIELD F.O.S. $= \frac{36000}{1960} = 18.4$

INTER-OFFICE MEMO
10-007-102

TO: G. Oiye, Dept. 4832

DATE: 2 December 1964
CNE:ns
4832-64-367

FROM: C. N. Epstein, Dept. 4832

SUBJECT: No. 4 TAA Design Package Addition

DISTRIBUTION: C. G. Boone, E. S. Chalpin, E. Eber, R. S. Foley, J. J. Marick, C. S. Mah, H. D. Tabakman, E. J. Vilter, J. H. Callahan, W. J. Zwicker, 4832 File

Enclosure: To addressee only

(1) Design Statement, SNAP-8 Turbine-Alternator Drive Spline. 15 pp. (Brown-lines, one set)

Enclosure (1) has been prepared for entry in the No. 4 TAA Design Package. This is an up-to-date statement of the basic design concept of the involute spline as applied in the SNAP-8 turbine-alternator drive system design. This basic statement will be augmented with additional material for this and other SNAP-8 TAA design packages, as observations of performance and continuing analysis give rise to supplementary data.

Additional copies of this design statement, if required, may be requested of Mrs. Jeannette Gredell, Dept. 4832 secretary.

C. N. Epstein

C. N. Epstein
Dept. 4832
SNAP-8 Division

QUADRILLE WORK SHEET

AEROJET GENERAL TIRE GENERAL

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

DATE ____

SUBJECT TAA DRIVE SPLINE BY CNE

WORK ORDER ____

TURBINE ALTERNATOR SPLINE DRIVE

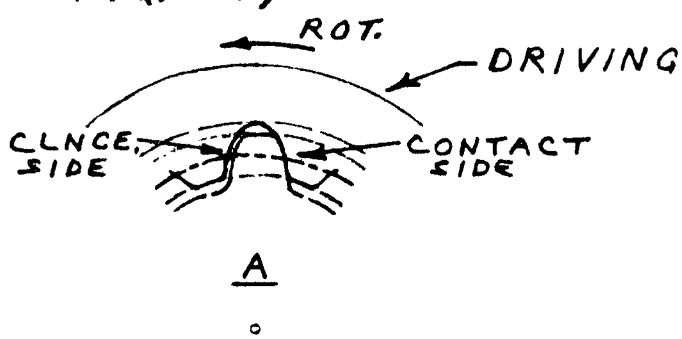
(INVOLUTE SPLINE COUPLING)

DESIGN STATEMENT

RE APPLICATION: SNAP-8 TURBINE ALTERNATOR ASSEMBLY NO. 4

GENERAL DESCRIPTION

THE TURBINE SHAFT IS COUPLED TO THE ALTERNATOR DRIVE QUILL SHAFT BY MEANS OF A CLEARANCE FIT INVOLUTE SPLINE. THE TORQUE INCIDENT TO THE DRIVING ACTION IS TRANSMITTED FROM THE INTERNAL SPLINE MEMBER WITHIN THE ALTERNATOR END OF THE TURBINE SHAFT TO THE EXTERNAL SPLINE MEMBER ON THE TURBINE END OF THE ALTERNATOR QUILL SHAFT. THE MOTION IS CCW WHEN VIEWED FROM THE TURBINE. (SEE FIG. - 1)



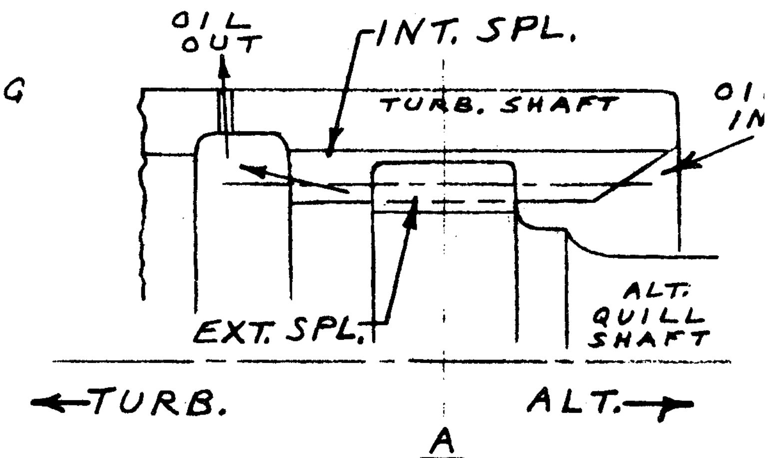


FIG. - 1

THE SPLINE MOVEMENT IS LUBRICATED DURING TAA OPERATION BY FLUID FROM THE 4TH LOOP L/C SYSTEM. THE FLUID IS CIRCULATED THROUGH THE SPLINE COUPLING FROM THE SCAVENGE FLOW LEAVING THE INBOARD (ALT. END) TURBINE BEARING CAVITY, AND IS SLUNG BACK INTO THE SCAVENGE SYSTEM AFTER PASSING THROUGH THE SPLINE, FROM THE COLLECTION ANNULUS IN THE TURBINE SHAFT AT THE OPPOSITE END OF THE SPLINE.

INVOLUTE SPLINE ELEMENTS

THE INVOLUTE CURVE, UPON WHICH THE SPLINE TOOTH DESIGN IS BASED, IS THE LOCUS OF A POINT ON A TANGENT WHICH IS ROTATED ON A CIRCLE CALLED THE <u>BASE CIRCLE</u>. ELEMENTAL FEATURES OF THE INVOLUTE GEOMETRY, APPLICABLE TO THIS DESIGN STATEMENT, ARE ILLUSTRATED IN FIG.-2. A SIGNIFICANT <u>PHYSICAL FEATURE</u> OF THE INVOLUTE APPLICATION IN TORQUE TRANSMISSION COUPLINGS IS THAT ALL NORMAL TOOTH FORCES RESOLVE THEMSELVES TANGENTIALLY TO THE COMMON <u>BASE CIRCLE</u> OF BOTH INTERNAL AND EXTERNAL SPLINE ELEMENTS. THE FULL SIGNIFICANCE OF THIS FEATURE WILL BE ELABORATED UPON IN A LATER TREATISE ON THIS DESIGN.

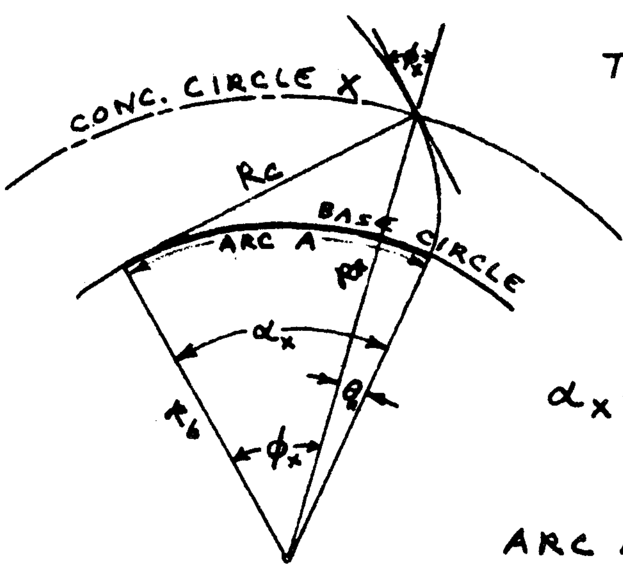


FIG.-2

THESE RELATIONSHIPS APPLY:

ϕ_x (PRESSURE ANGLE AT RAD. R_x) $= \cos^{-1} R_b / R_x$

$\theta_x =$ <u>INVOLUTE FUNCTION</u> OF ϕ_x

α_x (DEGREES ROLL, GENERATING TAN.) $= \phi_x + \theta_x$

$$\text{ARC } A = R_c \;\Big|\; \alpha_x = \frac{R_c}{R_b} \;\Big|\; \tan\phi_x = \frac{R_c}{R_b}$$

AND $\tan \phi_x = \phi_x + \theta_x$

INVOLUTE SPLINES HAVE FOR MANY YEARS BEEN STANDARDIZED ON A PITCH CIRCLE PRESSURE ANGLE OF 30°. THE PITCH CIRCLE OF AN INVOLUTE SPLINE IS THE CIRCLE OF AVERAGE DIAMETER BETWEEN THE MAJOR AND MINOR EFFECTIVE DIAMETERS OF THE SPLINE ELEMENTS. (SEE FIG. -3) INCLUDED AMONG REASONS FOR STANDARDIZATION ON THE 30° PRESSURE ANGLE IS THE FACT THAT THIS PORTION OF THE INVOLUTE CURVE IS FLATTER THAN THE PORTION USUALLY USED FOR GEAR DESIGN APPLICATIONS, AND UNIFORMITY OF ENGAGEMENT IS LESS SENSITIVE TO THE RATE OF CHANGE OF TOOTH CURVATURE WHICH OCCURS BETWEEN THE MINOR AND MAJOR DIAMETERS OF THE SPLINE.

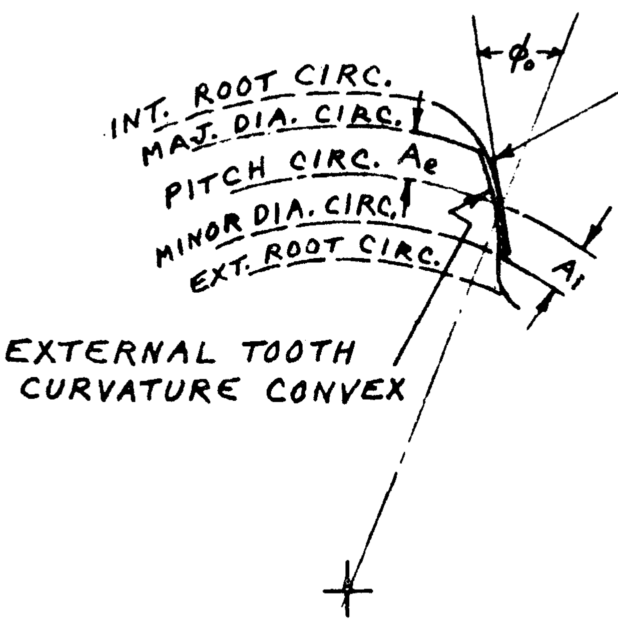


FIG. - 3

FOR A STANDARD INVOLUTE SPLINE:

$\phi_o = 30°$

$A_e = A_i$

THE DIAMETRAL PITCH OF AN INVOLUTE SPLINE IS EXPRESSED AS A FRACTION, i.e. — 10/20, 20/40, 24/48, ETC. THE NUMBER OF TEETH PER INCH OF SPLINE PITCH DIAMETER IS DESIGNATED IN THE NUMERATOR, AND CIRCULAR PITCH AND TOOTH THICKNESS ARE, ALSO CONTROLLED BY THIS FIGURE. THE DENOMINATOR CONTROLS THE RADIAL TOOTH PROPORTIONS OF THE SPLINE TOOTH. TYPICALLY, WHERE THE COMPLETE SPLINE PITCH DESIGNATION IS GIVEN AS P_D / P_R —

WHERE:	THESE EQUATIONS APPLY:
D_p = PITCH DIAM.	$D_p = N/P_D$
N = NO. TEETH	
p' = CIRC. PITCH	$p' = \pi/P_D$
t_o = BASIC TOOTH THICKNESS	$t_o = \pi/2P_D$
A_e = EXT. TOOTH ADDENDUM	
A_i = INT. TOOTH ADDENDUM	$A_e = A_i = 1/P_R$
C_R = RADIAL ROOT CLNCE.	$C_R = .8/P_R$

THE ABOVE RELATIONSHIPS ARE ALL APPLICABLE TO THIS DESIGN. WITH REFERENCE AGAIN TO FIGS. 1 AND 3, IT IS EVIDENT THAT TOOTH CONTACT, IN THE PLANE OF ROTATION IS, ON THE THEORETICAL BASIS, FROM THE MINOR DIAMETER TO THE MAJOR DIAMETER, AND IN THE CASE OF A STRAIGHT INVOLUTE SPLINE, WOULD PROVIDE A SURFACE BEARING BETWEEN THE CONVEX AND CONCAVE FACES OF THE CONTACTING TEETH.

REQUIREMENTS OF THE DESIGN APPLICATION

A - THE TAA DRIVE COUPLING MUST PROVIDE FOR EASE OF ASSEMBLY OF THE TURBINE AND ALTERNATOR UNITS INTO AN INTEGRAL UNIT.

B - THE TAA DRIVE COUPLING MUST ACCOMMODATE UP TO .010" OF PARALLEL MISALIGNMENT BETWEEN THE AXES OF ROTATION OF THE TURBINE AND ALTERNATOR ROTORS, AND AN ANGULAR OFFSET OF THE QUILL SHAFT FROM THE AXIS OF ROTATION OF THE ALTERNATOR ROTOR UP TO SIN^{-1} .010/L(QUILL SHAFT).

C - THE TAA DRIVE COUPLING MUST PROVIDE FOR FREEDOM OF AXIAL ADJUSTMENT DURING OPERATION DUE TO THERMAL DIFFERENTIAL EFFECTS WHICH MAY OCCUR BETWEEN THE HOUSING ASSEMBLY COMPONENTS AND THE INNER ROTATING ASSEMBLY COMPONENTS.

D - THE TAA DRIVE COUPLING MUST OCCUPY A CYLINDRICAL ENVELOPE WHICH WILL LEAVE THE THICKEST POSSIBLE SHELL BELOW THE INBOARD BEARING JOURNAL ON THE ALTERNATOR END OF THE TURBINE DRIVE SHAFT (SEE FIG. - 1) AND ADEQUATE CLEARANCE ABOVE THE MAXIMUM ANTICIPATED DIAMETER OF THE QUILL SHAFT. (THE QUILL SHAFT HAS INCREASED IN LENGTH, AND IN SHANK DIAMETER FROM .500" TO .650" IN THE COURSE OF ALTERNATOR DESIGN DEVELOPMENT.)

E - THE TAA DRIVE COUPLING, IN THE ORIGINAL DESIGN APPROACH, MUST PROVIDE FOR UNIVERSAL ACTION UNDER MAXIMUM TURBINE-ALTERNATOR MISALIGNMENT CONDITIONS, IN ORDER THAT RADIAL BEARING LOADS INCIDENT TO QUILL SHAFT DEFLECTIONS BE KEPT TO A MINIMUM. THAT IS, QUILL SHAFT RADIAL DEFLECTIONS ARE TO BE UNIDIRECTIONAL, AND NOT REVERSED.

F - THE OCCURRENCE OF UNIVERSAL ACTION IN THE TAA DRIVE COUPLING SHALL OCCASION NO UNDUE STRESS CONCENTRATIONS ON ANY PARTS OF THE COUPLING.

G - THE TAA DRIVE COUPLING SHALL BE CAPABLE OF SATISFACTORY PERFORMANCE IN TURBINE-ALTERNATOR DRIVE SERVICE FOR PERIODS IN EXCESS OF 10,000 HOURS.

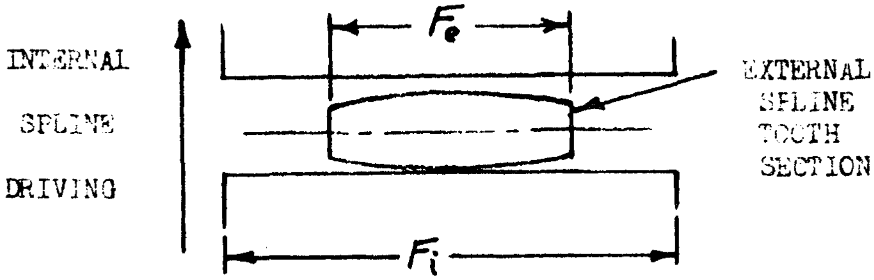
FEATURES OF THE APPLICABLE DESIGN

1 - THE SELECTED TAA DRIVE SPLINE IS A CLEARANCE FIT ASSEMBLY, TO ASSURE EASE OF ENGAGEMENT AT THE TIME OF TURBINE AND ALTERNATOR ASSEMBLY (REQUIREMENT A) AND TO ACCOMMODATE FREE RELATIVE AXIAL MOVEMENT OF THE TWO SPLINE COMPONENTS UNDER CONDITIONS OF TEMPERATURE DIFFERENTIAL FOR THE TAA HOUSING AND ROTATING ELEMENTS ASSEMBLIES (REQUIREMENT C).

2 - THE SELECTED TAA DRIVE SPLINE HAS EXTERNAL AND INTERNAL ROOT DIAMETER LIMITS WELL WITHIN THE ENVELOPE BOUNDARIES ESTABLISHED BY ADJACENT PARTS (RQMNT. D).

3 - THE NUMBER OF TEETH (20) IN THE SELECTED SPLINE DRIVE IS A SATISFACTORY MINIMUM NUMBER OF TEETH FROM THE STANDPOINT OF INVOLUTE CURVATURE CONTROL IN MANUFACTURE, A NUMBER OF TEETH SUCH THAT THE CORRESPONDING DIAMETRAL PITCH (20/40) TO OCCUPY THE AVAILABLE DESIGN ENVELOPE PROVIDES A TOOTH OF SUFFICIENT SIZE AND STRENGTH FOR THE APPLICATION, AND A MULTIPLE OF 4 WHICH IS A DESIRABLE FEATURE FOR A UNIVERSAL ACTING SPLINE MOVEMENT.

4 - THE TEETH ON THE EXTERNAL SPLINE MEMBER ARE AXIALLY CROWNED IN ORDER TO ACCOMMODATE UNIVERSAL ACTION IN THE SPLINE MOVEMENT (REQUIREMENTS B, E) AND TO ELIMINATE CORNERING STRESS CONCENTRATION EFFECTS ON THE ENDS OF THE EXTERNAL SPLINE TEETH (REQUIREMENT F). (SEE FIG. - 4)



$F_e < F_i$

$F_e = .5\, D_p$

FIG. - 4

5 - THE FACE WIDTH OF THE EXTERNAL SPLINE TOOTH IS EXCEEDED BY THE FACE WIDTH OF THE INTERNAL SPLINE TOOTH (SEE FIG. - 4), AND THE FORMER IS CENTRALLY LOCATED WITHIN THE LATTER IN THE TURBINE-ALTERNATOR ASSEMBLY, A DESIRABLE OVERLAPPING CONDITION FOR LUBRICANT RETENTION AND BEARING CONTROL IN A UNIVERSAL ACTING SPLINE (REQUIREMENTS F, G), AND AN ACCOMMODATION FOR RELATIVE AXIAL MOVEMENT OF THE SPLINE ELEMENTS DURING OPERATION (REQUIREMENT C).

6 - THE EXTERNAL SPLINE TOOTH FACE WIDTH IS HALF THE PITCH DIAMETER, A DESIRABLE RATIO FOR THE EXTERNAL ELEMENT OF A UNIVERSAL ACTING SPLINE, AS THE FLEXIBILITY ASSOCIATED WITH RELATIVELY SHORT FACE WIDTH PROMOTES EARLIER WEARING IN OF THE SPLINE MOVEMENT, FOR DISTRIBUTION OF THE LOADING OVER ALL THE TEETH, HELPING TO PROLONG TOTAL SPLINE WEAR LIFE (REQUIREMENT G).

7 - EXTERNAL AND INTERNAL SPLINE TOOTH SURFACES ARE NITRIDED AND CASE HARDENED TO PROLONG THE WEAR LIFE OF THE MOVEMENT (REQUIREMENT G), AND THE TOOTH FACES OF THE EXTERNAL SPLINE ARE GROUND TO REDUCE FRICTION ASSOCIATED

WITH AXIAL OR ANGULAR RELATIVE SPLINE MOVEMENTS.

8 - CHAMFERING OF THE LAND AND CONTOUR EDGES OF THE SPLINE TEETH IS CALLED FOR IN ORDER TO MINIMIZE LOCAL STRESS CONCENTRATIONS IN THE TEETH UNDER MOST EXTREME MISALIGNMENT CONDITIONS (REQUIREMENT F).

9 - THE SPLINE ELEMENT IS TO BE LUBRICATED BY A CIRCULATION OF ABOUT 1.2 LBS. PER MINUTE OF THE TAA L/O FLUID. THE IRRIGATING TYPE OF LUBRICATING SYSTEM (SEE FIG. - 1) HAS BEEN MOST SUCCESSFUL FOR UNIVERSAL ACTING INVOLUTE SPLINES DESTINED FOR LONG SERVICE APPLICATIONS (REQUIREMENT G).

DIMENSIONAL SPECIFICATIONS

DIMENSIONS SIGNIFICANT TO THE DEFINITION AND ANALYSIS OF THIS INVOLUTE SPLINE APPLICATION ARE AS FOLLOWS:

ITEMS COMMON TO EXTERNAL AND INTERNAL SPLINE ELEMENTS	DIMENSION	SYMBOL
NUMBER OF TEETH	20	N
DIAMETRAL PITCH	$\frac{20}{40}$	$P \; (= \frac{P_D}{P_R})$
CIRCULAR PITCH $(\frac{\pi}{P_D})$	.1571"	p'
PRESSURE ANGLE	30°	ϕ_0
PITCH DIAMETER $(\frac{N}{P_D})$	1.0000"	D_P
BASIC TOOTH THICKNESS $(.5\,p')$	.0785"	t_0
BASE CIRCLE DIAMETER $(D_P \cos \phi_0)$	.8660"	D_B

EXTERNAL SPLINE ELEMENTS	DIMENSION (") (AND TOLS.)	SYMBOL
OUTSIDE DIAMETER (MAJOR DIAM.)	$1.050\begin{cases}+.000\\-.005\end{cases}$	D_o
FACE WIDTH	$.500\begin{cases}+.020\\-.000\end{cases}$	F_e
RADIUS O.D. LAND EDGES OF TEETH	$.010\begin{cases}+.000\\-.004\end{cases}$	$R_{L/e}$
TOOTH THICKNESS (MAX. EF.)	.0770	T_e
TOOTH THICKNESS (MIN. DIM.)	.0742	T_D
ROOT DIAMETER	$.900\begin{cases}+.000\\-.010\end{cases}$	$D_{R/e}$
CROWN TEETH PER SIDE (EACH END)	$.0015\begin{cases}+.0005\\-.0005\end{cases}$	C_r
TRUE INVOLUTE FORM DIAM. (INNER MAX.)	.946	$D_{F/e}$

INTERNAL SPLINE ELEMENTS		
INSIDE DIAMETER (MINOR DIAM.)	$.950\begin{cases}+.005\\-.000\end{cases}$	D_i
FACE WIDTH (MIN.)	1.250	F_i
RADIUS I.D. LAND EDGES OF TEETH	$.010\begin{cases}+.000\\-.004\end{cases}$	$R_{L/i}$
SPACE WIDTH (MIN. EF.)	.0785	S_i
SPACE WIDTH (MAX. DIM.)	.0813	S_D
ROOT DIAMETER	$1.090\begin{cases}+.010\\-.000\end{cases}$	$D_{R/i}$
TRUE INVOLUTE FORM DIAM. (OUTER MIN.)	1.054	$D_{F/i}$

DESIGN ANALYSIS

THE OPERATION OF THE TURBINE-ALTERNATOR DRIVE CALLS FOR THE STEADY-STATE TRANSMISSION OF UP TO 94.5 mhp @ 12,000 RPM.

TORQUE (STEADY-STATE):

$$T = \frac{94.5 \times 12 \times 33,000}{2\pi \times 12,000} = 496\#\text{-}''$$

STALL TORQUE: $T_s = 2T = 992^{\#-''}$

IN SUBSEQUENT CALCULATIONS THE MINIMUM RADIAL DEPTH OF TOOTH ENGAGEMENT (h') WILL BE USED:

$$h' = .5(D_{o(MIN.)} - D_{i(MAX.)}) - (R_{L/e(MAX.)} + R_{L/i(MAX.)})(1 - \sin\phi_o)$$

$$h' = .035''$$

UNDER STALL TORQUE CONDITIONS, TAKING 25% OF TOTAL SPLINE TOOTH ENGAGEMENT AS APPLICABLE DURING THE EARLIEST PERIOD OF OPERATION:

SHEAR STRESS (S_s) AT PITCH CYLINDER:

$$S_{s(SPL.)} = \frac{T_s}{(.25N)(.5D_p)(F_e \times T_D)}$$

$$= 10,700 \text{ PSI}$$

UNDER STALL TORQUE CONDITIONS (CONT.)

$S_{s(SPL.)}$ COMPARES WITH MAX. SHEAR STRESS IN .646 DIA. (MIN.) SHANK OF QUILL SHAFT:

$$S_{s\,(SHAFT)} = \frac{16\ T_s}{\pi\ D_s^3} = 18,740 \text{ PSI}$$

$$\frac{S_{s\,(SPL.)}}{S_{s\,(SHAFT)}} = .571$$

COMPRESSIVE STRESS, DISTRIBUTED OVER 25% OF SPLINE TEETH:

$$S_c = \frac{T_s}{(.25N)(.5D_p)(F_e \times h')}$$

$$= 22,700 \text{ PSI}$$

BENDING STRESS, LOAD CARRIED BY 25% OF SPLINE TEETH:

$$S_b = \frac{T_s}{(.25N)(.5D_p)\ P'\ F_e\ y}$$

(y IS y_t FROM FIG.-5, P.-12, WHICH ASSUMES LOAD CONCENTRATED AT TIP OF TOOTH —WORST POSSIBLE CONDITION)

$$S_b = 16,100 \text{ PSI}$$

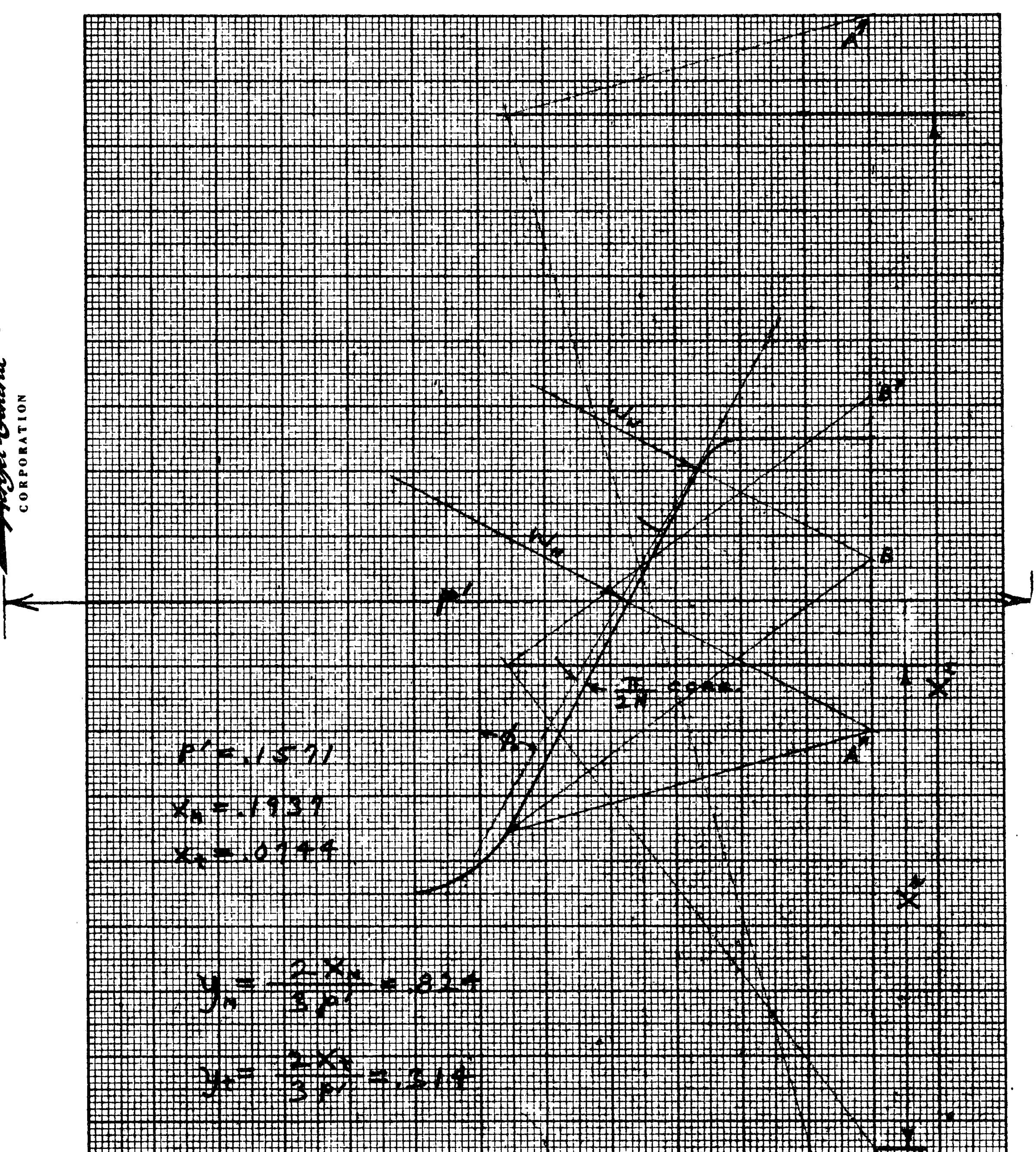


FIGURE - 5

RECTILINEAR REPRESENTATION OF EXTERNAL SPLINE TOOTH

SCALE = 50:1

IN THE LONG RUN, UNDER STEADY-STATE (94.5 mhp) CONDITIONS, AND AFTER THE SPLINE RUNNING-IN PERIOD HAS ACHIEVED CONTACT ON ALL TEETH, MAXIMUM ACTUAL OPERATING STRESSES SHOULD BE OF THE FOLLOWING ORDER:

CORR. FOR FULL N
CORR. FOR STRESS GRADIENT

$$S_{s(SPL.)} = \frac{10,700 \times .25 \times 2}{2} = 2,670 \text{ PSI}$$

CORR. FOR S.-S. LOAD

$$S_{s(SHAFT)} = .5 \times 18,740 = 9,370 \text{ PSI}$$

CORR. FOR S.-S. LOAD

$$\frac{S_{s(SPL.)}}{S_{s(SHAFT)}} = .286$$

CORR. FOR FULL N
CORR. FOR STRESS GRADIENT

$$S_c = \frac{22,700 \times .25 \times 2}{2} = 5,680 \text{ PSI}$$

CORR. FOR S.-S. LOAD

CORR. FOR FULL N

$$S_b = \frac{16,100 \times .25}{2} \left(\frac{.314}{.824}\right)^* = 767 \text{ PSI}$$

CORR. FOR S.-S. LOAD

* CORR. FOR TOOTH RADIAL CENTRALIZATION OF LOAD (SEE FIG.-5, P.-12)

ALTHOUGH THE LUBRICATING SYSTEM PROVIDED FOR THE DRIVE SPLINE MOVEMENT DURING TAA OPERATION SHOULD MINIMIZE THE POSSIBILITY OF METAL-TO-METAL CONTACTS BETWEEN THE ENGAGING SPLINE TEETH, THE EFFECTS OF INTERRUPTION OR FAILURE OF THE LUBE SYSTEM MUST BE EXAMINED. IF THIS SHOULD OCCUR DURING THE EARLY PERFORMANCE LIFE OF THE SYSTEM, WITH 25% OF THE TEETH IN CONTACT:

RADIUS OF CURVATURE OF CROWNED EXTERNAL TOOTH AT PITCH DIAMETER (R_a):

$$R_{c\,(MIN.\,EFF.)} = \frac{F_e^{\,2}}{8\,C_{r\,(MAX.)}} = 15.62''$$

SPECIFIC COMPRESSIVE STRESS IN REGIONS OF TOOTH CONTACT;

$$S_c' = .591\left(\frac{T\,E}{(.25N)(.5D_p)\,h'\,R_c}\right)^{\frac{1}{2}}$$

WITH $E = 30 \times 10^6$ PSI

$$S_c' = 43{,}600 \text{ PSI}$$

IF METAL-TO-METAL CONTACTS BETWEEN THE ENGAGING SPLINE TEETH SHOULD OCCUR DURING THE LATER PERFORMANCE LIFE OF THE SYSTEM, WHEN ALL OF THE

SUBJECT TAA DRIVE SPLINE BY CNE

TEETH ARE IN CONTACT:

$$S_c'' = .591 \left(\frac{T\ E}{N(.5 D_p)\, h'\, R_c} \right)^{\frac{1}{2}}$$

$$= 21,840 \text{ PSI}$$

MECHANICAL PROPERTIES GIVEN FOR THE TURBINE SHAFT (INTERNAL SPLINE) AND QUILL SHAFT (EXTERNAL SPLINE) MATERIALS ARE AS FOLLOWS:

PART	MATERIAL	S_t (KPSI) RT-.2% YLD.	S_c (KPSI) RT-.2% YLD.	S_s (KPSI) RT
TURB. SHAFT	4340 STEEL	142	156*	100
ALT. QUILL SHAFT	NITRALLOY-135	132	145*	95

*NITRIDED CASE S_c > ABOVE VALUES

<u>THIS DESIGN STATEMENT TO BE AUGMENTED</u>

10-047-009 (REV. 6/63)

DIVISION SNAP-8

TM 395:64-2-253

DATE 5 November 1964

W.O. 0741-11-2000

TECHNICAL MEMORANDUM

AUTHOR(S): C. S. Mah

TITLE: TAA Critical Speed

ABSTRACT

To insure that the turbine-alternator assembly (TAA) would not fail because of vibration, the natural frequency of the TAA in torsion and the natural frequency of the turbine (TA) in several modes were calculated.

The natural frequency of the TA rotor in flexure, on the basis of an assumed bearing stiffness of 6×10^5 lb/in., was 20,400 cycles/min. The bearing stiffness of 6×10^5 lb/in. was based on vendor-supplied data and calculations.

Other calculated TA natural frequencies were as follows:

1. Natural frequency of TAA rotor in torsion - 3600 cpm
2. Natural frequency of composite turbine housing in lateral direction - 22,500 cpm
3. Natural frequency of turbine rotor in axial direction - 69,000 cpm

Excitation of vibrations from the turbine wheels, the turbine nozzle, and the bearings were calculated; they were seen to cause no resonance.

APPROVED:

DEPARTMENT HEAD E S Chalpin

E. S. Chalpin

CONTENTS

I. INTRODUCTION

The Turbine-Alternator Assembly (TAA), as a structure, has natural frequencies in vibration. If these natural frequencies are excited to resonance, structural failure of the TAA can occur. To insure that the TAA dynamics do not excite undesirable vibrations, several modes of TAA vibrations were calculated. The most important of these vibration checks consist of computing the natural frequency of the rotors in flexure, the natural frequencies of the rotors in torsion, the natural frequency of the rotors in the axial direction, and the natural frequency of the housing.

The TAA shafts' flexural, natural frequencies are dependent on very complex fourth-order, differential equations, so a digital computer was used for these calculations. Other natural frequencies, being less complicated to calculate or less important, were calculated by hand.

In this Technical Memorandum only the TAA torsional, natural frequency and various turbine assembly (TA) natural frequencies are presented. The alternator's natural frequencies are presented under separate cover as General Electric Report No. 64GL125, "Bearing Evaluation and Critical Speed Calculations for the SNAP-8 Alternator," by J. M. McGrew, dated 31 August 1964.

II. CALCULATION OF NATURAL FREQUENCIES

A. TA FLEXURAL, NATURAL FREQUENCY

The TA flexural, natural frequency, commonly referred to as "critical speed," is dependent on three main factors: shaft geometry, temperature distribution along the length of the shaft, and bearing stiffness. The shaft geometry is a function of the turbine mechanical design; the temperature distribution along the shaft is obtained from a thermal analysis of the TA, (see TM 394:63-147); and the bearing stiffness is obtained from vendor data, (see Appendix A).

To convert these factors into a TA flexural, natural frequency, the Aerojet IBM 7090 Computer Program 272C, "Fundamental Lateral Vibration Modes," was used. This program is based on a method of calculating the natural frequency of a beam as developed by MyKelstad and others. The method is a direct extension of the Holzer method, familiar in torsional calculations of flexural vibration. The details of the method may be briefly summarized as follows:

1. The beam is first divided into a number of convenient sections (stations).
2. The mass of each section is calculated, divided into halves, and these two halves are concentrated at the two ends of each section. (The beam is then weightless between cuts, and at each cut there is a concentrated mass equal to the sum of the masses of the adjacent sections.
3. A natural frequency is assumed, and calculations are made from section to section along the beam. The calculations are made with a selected set of end conditions. For instance, for a free-free beam, the shear force and the moment at each end are equal to zero. If the selected frequency does not yield a result which meets both end conditions, new frequencies are selected and the calculations are iterated until the end conditions are met.
4. A spring force is added to the section where there is a bearing restraint. This spring force is based on bearing stiffness values bracketing values recommended by vendors.

In the actual analysis, two assumptions were made. One —the curvic couplings of the turbine wheels have only 80% of the stiffness of an undivided shaft. Two -- components such as press fit sleeves have only 65% of the stiffness of one-piece shafts.

The actual division of the shaft into stations for computation is shown in Figure 1. The stations were selected at the following points:

1. Diameter change points
2. Bearing reaction points
3. Points where the sleeve diameter changed
4. Enough other points so that there was at least one point for every 4% of shaft length.

The computations were done in the IBM 7090 digital computer. In Appendix B, the input requirements for computation are outlined. Included are restrictions and instructions for usage.

Appendix C shows the actual computational method used in the program. Included is the definition of the transfer matrix used to solve the simultaneous equations.

Appendix D shows the physical dimensions of the shaft and the physical properties of the shaft material at the different chosen stations of computation.

Appendix E shows the computer print-out of the input and the output data. The output data includes results based on four different bearing stiffnesses: 1×10^5, 6×10^5, 1×10^6, and 1×10^7 lb/in.

B. TAA TORSIONAL, NATURAL FREQUENCY

The calculation of the TAA torsional, natural frequency was as follows:

1. The polar moment of inertia of the turbine is calculated; the polar moment of inertia of the alternator is obtained from the General Electric Report No. 3-9-11-63.
2. The natural frequency based on the quill shaft is calculated.
3. The natural frequency based on the turbine shaft is calculated. The alternator shaft is assumed to be rigid.
4. The TAA torsional, natural frequency is obtained by Dunkerly's Equation.

The calculations are shown in Appendix F.

C. NATURAL FREQUENCY OF COMPOSITE TURBINE HOUSING IN THE LATERAL DIRECTION

The composite turbine housing is shown in Drawing No. 092100. The main feature of it is the cold frame which bridges the bearing housing and the inlet housing. The cold frame consists of four cantilever arms. These arms are assumed to be the least rigid in the housing assembly for the calculation of the lowest natural frequency.

The method of calculation involves the calculation of the deflection of the housing as a function of load. This deflection-load relation, (which is really a spring constant), is then converted to a natural frequency with the simple spring-mass relation.

The deflection of the housing was calculated by the method of virtual work, a method of analysis based on the classical procedures developed by A. Castigliano (see Appendix G).

D. NATURAL FREQUENCY OF TURBINE ROTOR IN THE AXIAL DIRECTION

The natural frequency of the turbine rotor in the axial direction may be calculated on the basis of a simple spring-mass system. In this case, the mass consists of the turbine rotor, and the spring consists of the preload springs on the bearings. The actual calcuations are shown in Appendix H.

III. RESULTS

The results of the computer analysis of the turbine (TA) flexural, natural frequency are presented in Figure 2. For the -1 Model of the TA, the natural frequency increases from 12,200 rpm at a bearing stiffness of 10^5 lb/in. to 24,000 rpm at a bearing stiffness of 10^7 lb/in. The most probable value is 20,400 rpm at a bearing stiffness of 6×10^5 lb/in.

The above result is partly supported by the results of the TAA tests with nitrogen as the working fluid. In one test, (Test D-5-R-8 in GN_2S-1), the turbine was run up to a speed of 15,000 rpm; and while vibrations increased, there was no indication that the TA was operating near critical speed.

The results of the torsional, natural frequency calculations showed that the rotor system will have a natural frequency of 3600 rpm.

The 3600 rpm torsional, natural frequency, being lower than the 12,000 rpm design speed of the TAA, will be encountered by the TAA during both startup and shutdown. However, the present startup and shutdown procedures call for passing the 3600 rpm point quickly, and no difficulty should be expected.

The natural frequency of the composite turbine housing (in the lateral direction) was calculated to be 22,500 cpm. The natural frequency of the turbine rotor in the axial direction was calculated to be 69,000 cpm.

The turbine nozzles, wheels and the bearings will provide excitation at frequencies other than the fundamental 12,000 cpm of the TAA running speed. The exciting frequencies are as follows:

		Exciting Frequency CPM
A.	TURBINE NOZZLES	
	1. First and Second Stage	290,000
	2. Third and Fourth Stage	290,000
B.	TURBINE WHEELS	950,000
C.	BEARINGS (See Appendix I)	
	1. Ball Spin Frequency	29,000
	2. Cage Assembly Rotation	4,850
	3. Relative Speed Between the Train and the Rotating Inner Ring	7,150
	4. Irregularity on Inner Race	93,000
	5. Irregularity on Outer Race	63,000

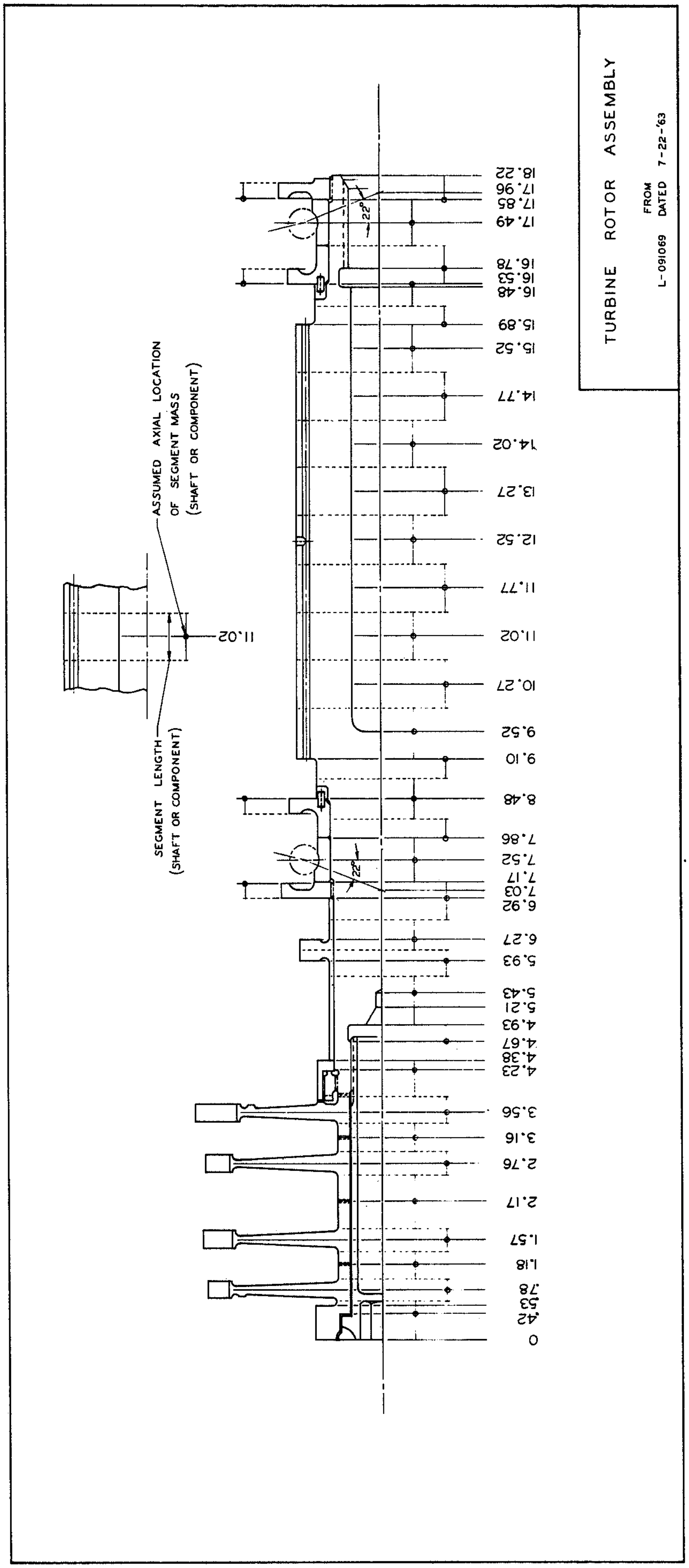
No resonance is seen to exist; therefore, there should be no excessive vibration at the TAA design speed of 12,000 rpm.

<u>BIBLIOGRAPHY</u>

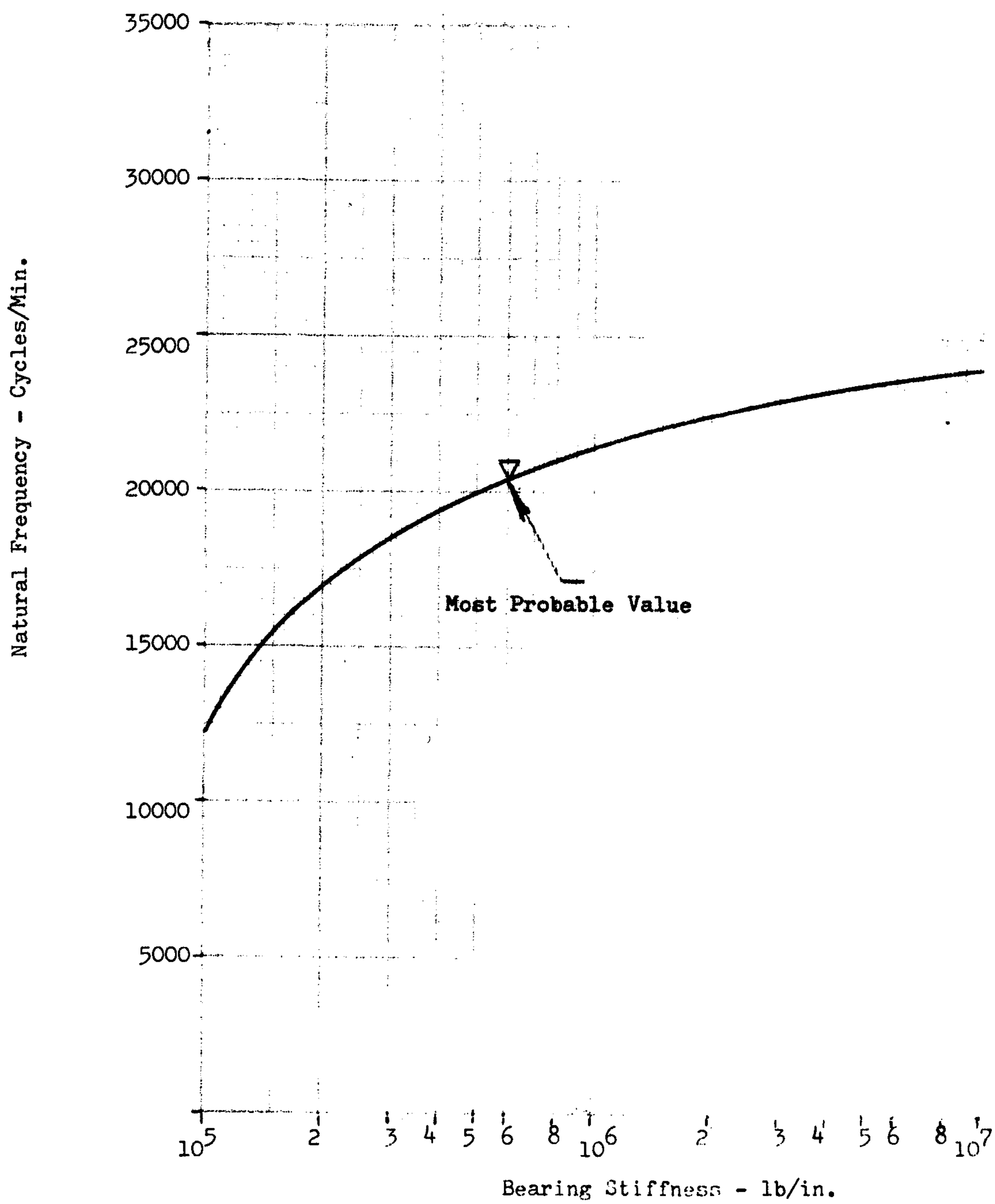
1. CRITICAL SPEEDS OF ROTATING COMPONENTS OF SNAP-8 PDA-1 AND PDA-1B AS FUNCTIONS OF BEARING STIFFNESS,
Aerojet Report No. 2137, November 1961

2. A REPORT TO JOINT AEC-NASA CONFERENCE ON BEARING-SHAFT DYNAMICS FOR OPERATION IN SPACE,
Aerojet Report No. 2348, July 1962

3. Memorandum from C. L. Svoboda to C. G. Boone,
"SNAP-8 CRITICAL SPEED AND SHAFT DYNAMICS COMPUTER PROGRAM,"
4 January 1963


TURBINE ROTOR ASSEMBLY
FROM L-091069 DATED 7-22-'63
ASSUMED AXIAL LOCATION OF SEGMENT MASS (SHAFT OR COMPONENT)
SEGMENT LENGTH (SHAFT OR COMPONENT)
11.02
22°
22°
0
.42
.53
.78
1.18
1.57
2.17
2.76
3.16
3.56
4.23
4.38
4.67
4.93
5.21
5.43
5.93
6.27
6.92
7.03
7.17
7.52
7.86
8.48
9.10
9.52
10.27
11.02
11.77
12.52
13.27
14.02
14.77
15.52
15.89
16.48
16.53
16.78
17.49
17.85
17.96
18.22

TA ROTOR (-1 MODEL) FLEXURAL NATURAL FREQUENCY
FOR DIFFERENT BEARING STIFFNESSES
COMPUTER ANALYSIS 30 AUGUST 1963, SN8TA DRW L910697/22/63



10-087-118

Figure 2

APPENDIX A

BEARING RADIAL STIFFNESS SUMMARY
AGC AND VENDOR CALCULATIONS

(J. Rogoza)

APPENDIX A

BEARING RADIAL STIFFNESS SUMMARY

AGC AND VENDOR CALCULATIONS

(J. Rogoza)

Bearing - Size 208 angular-contact

Preload - 50 pounds

Radial Load - 50 pounds

	Source	Contact Angle	Radial Stiffness Lb/In.
(1)	AGC	15°	8.2×10^5
(2)	Barden	14°	8.8×10^5
(3)	Fafnir	12°	7.3×10^5
(4)	ITI	25°	6.7×10^5

Items (1), (2) and (3) are based on the analytical method of A. B. Jones in "Analysis of Stresses and Deflections," New Departure, 1946. Item (2) is further modified by the vendor's experimental data.

Item (4) is based on computer analysis, which included effect of centrifugal ball force at 12,000 rpm.

Recommend use of conservative value of 6.0×10^5 lb/in. for calculation of turbine assembly critical speed.

APPENDIX B

FUNDAMENTAL LATERAL VIBRATION MODES

(F. N. Olsen)

PROGRAM 272 A

FUNDAMENTAL LATERAL VIBRATION MODES

I. PURPOSE:

This program is designed to determine, by means of an iterative technique, the natural frequencies of a beam-like structure, which is described by a series of lumped masses, connected together by springs. It provides, in addition to the natural frequencies, the associated shears, moments, slopes and deflections, for each associated normal mode, scaled by an arbitrary factor.

II. METHOD:

The method used is that developed by Mykelstad, and outlined in his book Fundamentals of Vibration Analysis, McGraw Hill, 1956.

The recursion formulae are modified to include the effects of shear deflection, rotary inertia, and elastic foundation. In addition, the recursion is put into the form of a 'Transfer Matrix', in order to make use of matrix algebra. The transfer matrix is described completely in appendix A.

The method is essentially one of plotting a residual boundary condition which should equal 0 (moment, in the case of free-free end conditions) as a function of the frequency, and applying an interval-halving technique to home in on a root when a sign change in the residual is observed.

III. INPUT:

A. Control Card

	Item	Card Col.	Format
1.	Title Information	1-36	6A6
2.	Frequency Estimate, ω_0	37-48	E12.8
3.	Initial Frequency Step, $\Delta\omega$	49-60	E12.8
4.	Number of Stations, NS	61-63	I3
5.	Boundary Condition Code, NB	64-66	I3
6.	First Mode Number, NF	67-69	I3
7.	Last Mode Number, NL	70-72	I3

Title can be any legal Hollerith Characters. ω_0 is in radians/sec, and provides a starting point for the search for natural frequencies. It must, therefore, be smaller than the first natural frequency desired.

$\Delta\omega$ is the amount by which the frequency is stepped initially. It is modified by the program as execution proceeds. ($\Delta\omega$ = .05 -- .10 x ω_0 has worked well in the past).

NS is the number of stations, (axial coordinates) used in describing the system. ($5 \leq NS \leq 100$).

NB is the code used to specify boundary conditions, as follows:

NB	Left End	Right End	($X_{left\ end} < X_{right\ end}$)
1	Free	Free	
2	Fixed	Free	
3	Fixed	Fixed	
4	Fixed	Pinned	
5	Pinned	Pinned	
6	Pinned	Free	
7	Free	Fixed	
8	Pinned	Fixed	
9	Free	Pinned	

B. Data Cards

The Number of data cards must be NS, one for each station. All the input parameters listed below are expected to be in E12.8 Format.

Item	(On the i-th data card)	Card Col
1.	X, inches	1-12
2.	WT, lbs	13-24
3.	EI, lb-in^2	25-36
4.	I_z, lb-in^2	37-48
5.	AG/K, lbs	49-60
6.	KS, lb/in	61-72

X is the distance from some point on the beam axis to the i-th station.

WT is the weight of the mass lumped at the i-th station.

EI is the bending stiffness between stations (i) and (i + 1).

E = modulus of elasticity.
I = moment of inertia of area of cross section.

I_z is the moment of inertia of the i-th mass about an axis perpendecular to the plane of bending, and through the neutral axis.

AG/K is the shear stiffness between stations (i) and (i + 1).

A = cross section area
G = shear modulus
K = constant accounting for distribution of shear stress on the cross section.

KS is the elastic foundation spring constant at the i-th station.

C. Data Preparation

1. Stations on the beam must be chosen so as to give a reasonable representation of the EI distribution. Where discontinuities occur, it is advisable to choose 3 stations to describe the discontinuity; one on either side of, and one on, the discontinuity.

C. Data Preparation (Continued)

2. Weights must be lumped so that those at the first and last stations are zero.

3. In order to describe sections of the beam which are infinitely stiff in shear of bending, the program will accept "zero" for either AG/K or EI, and treat it as if it were an infinitely large number. A stiffness which is actually zero, such as a pin joint, is not acceptable.

4. X, WT, EI and/or AG/K are the only required inputs to the program. I_z and KS need be input only when necessary to describe the physical system, and then only at selected stations.

IV. OUTPUT:

1. All input information is written out.

2. During the search for natural frequencies, each frequency and its accompanying residual is written out.

3. When a natural frequency is found, it is written out, both in radians/sec and cycles/sec. This is followed by output of the shear, moment, bending slope, total slope, and total deflection at each axial coordinate. These outputs are in two forms:

a. The output parameters are scaled such that the deflection will be unity at some point. If there is a free end, the deflection will be unity at that end. If there is no free end, the maximum deflection will be scaled to unity.

b. The values output in (a) will be scaled by a constant β, chosen to make

$$\beta \sum_{i=1}^{NS} (m_i y_i^2 + I_{z_i} \theta_i^2) = M$$

which is the total mass, where m is the mass at the i-th station, y is the deflection at the i-th station, I_z is the rotary moment of inertia at the i-th station, and θ_i is the bending slope at the i-th station.

4. BCD card output is written for each natural frequency on drive B1 as follows:

All data is written in 1PE12.5 Format

Card 1

Item	Card Col
Total weight	1-12
Natural Frequency, rad/sec	13-24
β, in (3.b) above	25-36

Card 2-Card NS+1

Item	Card Col
Axial Coordinate	1-12
Weight	13-24
Shear	25-36
Moment	37-48
Bending Slope	49-60
Deflection	61-72

Where shear, moment, slope, and deflection are scaled as in (3.a) above.

5. When all requested natural frequencies have been found, the following output is printed:

The generalized mass, generalized stiffness, and $\Sigma m_i y_j$ for each natural frequency, followed by an "Orthogonality Matrix" [A], where

$$a_{ij} = \sum_{k=1}^{NS} (m_k y_k^i y_k^j + I_{z_k} \theta_k^i \theta_k^j),$$

where the superscripts indicate mode number. For a "perfect" solution,

$$a_{ij} = 0, \ i \neq j; = 1, \ i=j$$

hence the size of the off-diagonal terms gives a measure of accuracy.

V. RESTRICTIONS:

1. The number of stations used, NS, must be greater than 4 but less than 101.

2. Where two natural frequencies are close together, it is possible that one of them may be missed. Hence a careful examination of the output deflection curves is necessary to make sure that no modes have been missed. This is a particular problem when elastic foundation spring constants are utilized. They introduce infinite discontinuities in the residual curve, and while the program will jump out of such a region when it discovers it, it may, in so doing, pass over a root at the same time. A rerun, starting in the region where a root was missed will usually result in finding the missing root.

3. Weight at the first and last stations must be zero!

VI. USAGE:

1. Computer 32K 709/7090

2. Fortran II, version 2, or version 3 (IBSYS), operating system.

3. Tapes:
Input-Logical 5, Physical A2,
(Physical A2 is specified since the Fap program checks for EOF on

3. Tapes: (Continued)

A2 before rewinding and unloading BCD card output tape)

Print Output-Logical 6
Punch Output-Logical 8-Physical B1
Scratch-Physical B2, B3, A5
Also requires on-line printer

4. As many cases as desired can be stacked on the input taps.

5. Format Specifications are as described in I.B.M. manual C28-6054, 709/7090 Fortran Programming System.

APPENDIX C

DEFINITION OF THE TRANSFER MATRIX AND METHOD OF CALCULATION

APPENDIX C

Definition of the Transfer Matrix and Method of Calculation.

A. Transfer Matrix

The transfer matrix used in applying the Mykelstad Method in computer programs 272A, 272B is defined as follows.

1. It is the operator which defines the (i+1) state vector s_{i+1}, in terms of the ith state vector, s_i, as shown below where the state vector is composed of shear, moment, slope, and deflection.

$$|S|_{i+1} = [T]_i \cdot |S|_i = [T]_i \cdot [T]_{i-1} \cdot |S|_{i-1} \dots = \left[\prod_{j-1}^{i} [T]_j \right] \cdot |S|_1 \quad .$$

and

2. The elements of $[T]_i$ are as follows:

$$t_{11} = 1.0$$

$$t_{12} = t_{13} = 0$$

$$t_{14} = m_i\omega^2 - KS_i$$

$$t_{21} = \Delta X_i = X_{i+1} - X_i$$

$$t_{22} = 1.0$$

$$t_{23} = -I_{Zi}\omega^2$$

$$t_{24} = \Delta X_i, \ t_{14} = \Delta X_i \ (m_i\omega^2 - KS_i)$$

$$t_{31} = \frac{(\Delta X_i)^2}{2\ EI_i}$$

$$t_{32} = \frac{\Delta X_i}{EI_i}$$

$$t_{33} = 1. - \frac{\Delta X_i \ t_{23}}{EI_i} = 1. - \frac{\Delta X_i \ I_{Zi}\omega^2}{EI_i}$$

$$t_{34} = \frac{\Delta X_i}{2EI_i} \ t_{24} = t_{31} \ t_{14} = \frac{(\Delta X_i)^2}{2EI_i} \ (m_i\omega^2 - KS_i)$$

$$t_{41} = \frac{\Delta X_i}{3} \cdot t_{31} - \frac{\Delta X_i}{(AG/K)_i} = \frac{(\Delta X_i)^3}{6\ EI_i} - \frac{\Delta X_i}{(AG/K)_i}$$

$$t_{42} = t_{31} = \frac{(\Delta X_i)^2}{2EI_i}$$

$$t_{43} = \Delta X_i - \frac{(\Delta X_i)^2 \; I_{Z_i} \omega^2}{2\ EI_i}$$

$$t_{44} = 1 + t_{41} \cdot t_{14} = 1. + \left[\frac{(\Delta X_i)^3}{6EI_i} - \frac{\Delta X_i}{(AG/K)_i}\right] \cdot (m_i \omega^2 - KS_i)$$

where

ΔK_i is the distance between stations i and i+1, inches

EI_i is the bending stiffness between station i and i+1, lb-in^2

m_i is the mass at station i, lb-sec ^{2}/in

$(AG/K)_i$ is the shear stiffness between stations i and i+1, lbs

I_{Z_i} is the rotary inertia of m_i, at station i, in-lb-sec^2

KS_i is the elastic foundation spring constant at station i, lb/in (not used in branched-beam program)

ω is a particular frequency, radians/sec

B. Method of Calculation

In tne following discussion, a system with free-free end conditions is assumed.

1. Determination of the residual.

For a particular frequency, ω, the product matrix π_{N-1} is formed,

where
$$\pi_{n-1} = \prod_{i=1}^{n-1} [T]_i = [T]_{n-1} \cdot [T]_{n-2} \cdots\cdots [T]_2 \cdot [T]_1$$

Since the boundary condition to be applied is free-free, the shear and moment at each end of the beam must be zero if this is a natural frequency.

The following technique is applied:

A state vector $S_1 = \begin{vmatrix} 0 \\ 0 \\ \theta_1 \\ 1. \end{vmatrix}$ is assumed with θ_1 arbitrary

then the operation
$$S_n = \begin{vmatrix} V_n \\ M_n \\ \theta_n \\ Y_n \end{vmatrix} = \pi_{n-1} \begin{vmatrix} 0 \\ 0 \\ \theta_1 \\ 1. \end{vmatrix}$$ is performed symbolically

Since, for the boundary condition to be satisfied, V_n, M_n must be zero, we set $V_n = 0$, and solve the equation

$$V_n = 0 = \pi^{11} \cdot 0 + \pi^{12} \cdot 0 + \pi^{13} \theta_1 + \pi^{14} \cdot 1.$$

for θ, i.e., $\theta_1 = -\dfrac{\pi^{14}}{\pi^{13}}$

thus M_n = Residual $= \pi^{21} \cdot 0 + \pi^{22} \cdot 0 + \pi^{23} \theta_1 + \pi^{24} \cdot 1.$

The new residual is compared with the last. When a sign change is noted, a root is assumed to lie between the last two frequencies. Successive iterations are then used to "home-in" on the root.

APPENDIX D

DATA FOR L-091069 SHAFT AND ROTOR ASSEMBLY

(W. J. Zwicker)

DATA FOR SHAFT

Station	Radius Outer	Radius Inner	I	E X 10^6	EI X 10^6	Area	G X 10^6	K	AG/K X 10^6	Weight
0	.79	.73	.0829	23.00	1.526	.2865	8.712	1.881	1.327	0
.42	.79	.53	.2439	23.00	4.488	1.0782	8.712	1.772	5.301	.2171
.53	.69	.50	.1289	23.02	2.374	.7103	8.720	1.968	3.147	0
.78	"	"	"	23.04	2.376	"	8.728	"	3.151	.0732
1.18	"	"	"	23.18	2.391	"	8.781	"	3.169	.0925
1.57	"	"	"	23.75	2.449	"	8.997	"	3.247	.0775
2.17	"	"	"	25.08	2.376	"	9.500	"	3.429	.1829
2.76	"	"	"	25.68	2.648	"	9.728	"	3.511	.0732
3.16	"	"	"	26.15	2.697	"	9.906	"	3.575	.0947
3.56	.69	"	.1289	26.60	2.743	.7103	10.076	1.968	3.637	.0947
4.23	.734	"	.1790	26.56	4.754	.9071	10.061	1.955	4.668	.1461
4.38	"	.50	.1790	26.75	4.788	.9071	10.133	1.955	4.702	0
4.67	"	.51	.1748	27.09	4.735	.8754	10.262	1.960	4.583	.1443
4.93	"	.18	.2271	27.33	6.207	1.5907	10.353	1.637	10.060	0
5.21	"	.10	.2279	27.60	6.290	1.6611	10.455	1.511	11.493	0
5.43	"	0	.2280	27.78	6.334	1.6925	10.523	1.333	13.361	.3502
5.93	"	"	"	28.08	6.402	"	10.637	"	13.506	.2019
6.27	.734	"	.2280	28.23	6.436	1.6925	10.694	"	13.578	.2307
6.92	.76	"	.2620	28.44	7.451	1.8146	10.773	"	14.665	.2867
7.03	.787	"	.2620	28.44	7.451	1.8146	10.773	"	14.665	0
7.17	"	"	.3013	28.50	8.587	1.9458	10.796	"	15.795	0
7.52	"	"	"	28.56	8.605	"	10.819	"	15.792	.3868
7.86	.787	"	.3013	28.60	8.617	1.9458	10.834	"	15.815	.1713
8.48	.975	"	.7097	28.64	20.326	2.9865	10.849	"	24.306	.3831
9.10	1.30	0	2.2432	28.65	64.268	5.3093	10.853	1.333	43.227	.2714
9.52	"	.50	2.1941	"	62.861	4.5239	"	1.779	27.599	.9970
10.27	"	"	"	"	"	"	"	"	"	1.0150
11.02	"	"	"	"	"	"	"	"	"	.9636
11.77	"	"	"	"	"	"	"	"	"	"
12.52	"	"	"	"	"	"	"	"	"	"
13.27	"	"	"	"	"	"	"	"	"	"
14.02	"	"	"	"	"	"	"	"	"	"
14.77	"	"	"	"	"	"	"	"	"	"

DATA FOR SHAFT
(cont.)

Station	Radius Outer	Radius Inner	I	E X 10^6	EI X 10^6	Area	G X 10^6	K	AG/K X 10^6	Weight
15.52	1.30	.50	2.1941	28.65	62.861	4.5239	10.853	1.779	27.599	.9636
15.89	.995	"	.7208	"	20.650	2.3248	"	1.867	13.514	.2129
16.48	.995	.60	.6680	"	19.138	1.9793	"	1.822	11.790	0
16.53	.787	"	.1995	"	5.716	.8148	"	1.978	4.471	.2287
16.78	"	.50	.2522	"	7.225	1.1604	"	1.939	6.495	.1591
17.49	.787	"	"	"	7.225	1.1604	"	1.939	6.495	.2439
17.85	.73	.50	.2522	"	4.985	.8888	"	1.957	4.929	.0883
17.96	.73	"	.1740	28.65	4.985	.8888	10.853	1.957	4.929	0
18.82	0	0								0

DATA FOR COMPONENTS

Station	Radius Outer	Radius Inner	I	E X 10^6	EI X 10^6	Area	G X 10^6	K	AG/K X 10^6	Weight
4.38	.81	.734	.1101	26.75	1.914	.3686	10.133	1.998	1.215	0
4.67	"	"	"	27.09	1.939	"	10.262	"	1.230	.0619
4.93	"	"	"	27.33	1.956	"	10.353	"	1.242	0
5.27	"	"	"	27.60	1.975	"	10.455	"	1.253	0
5.43	.81	.734	.1101	27.78	1.988	.3686	10.523	1.998	1.262	.0628
6.27	.81	.734	.1101	28.23	2.020	.3686	10.694	1.998	1.282	.1900
7.17	1.00	.787	.4841	28.50	8.968	1.1961	10.796	1.983	4.233	.3094
7.52	.95	"	.3384	28.56	6.282	.8895	10.834	1.989	3.149	.2348
7.86	.95	.787	.3384	28.60	6.291	.8895	10.849	1.989	3.154	.2038
16.53	.95	.787	.3384	28.65	6.302	.8895	10.853	1.989	3.155	.1596
16.78	.95	"	.3384	"	6.302	.8895	"	1.989	3.155	.2038
17.49	1.00	.787	.4841	28.65	9.015	1.1961	10.853	1.983	4.255	.2348

DATA TOTALS

Station	EI X 106			AG/K X 10^6			Weight		
	Shaft	Comp.	Total	Shaft	Comp.	Total	Shaft	Comp.	Total
0	1.526		1.526	1.327		1.327	0		0
.42	4.488		4.488	5.301		5.301	.2171		.2171
.53	2.374		2.374	3.147		3.147	0		0
.78	2.376		2.376	3.151		3.151	.0732		.0732
1.18	2.391		2.391	3.169		3.169	.0925		.0925
1.57	2.449		2.449	3.247		3.247	.0775		.0775
2.17	2.376		2.376	3.429		3.429	.1829		.1829
2.76	2.648		2.648	3.511		3.511	.0732		.0732
3.16	2.697		2.697	3.575		3.575	.0947		.0947
3.56	2.743		2.743	3.637		3.637	.0947		.0947
4.23	4.754		4.754	4.668		4.668	.1461		.1461
4.38	4.788	1.914	6.702	4.702	1.215	5.917	0	0	0
4.67	4.735	1.939	6.674	4.583	1.230	5.813	.1443	.0619	.2062
4.93	6.207	1.956	8.163	10.060	1.242	11.302	0	0	0
5.21	6.290	1.975	8.215	11.493	1.253	12.746	0	0	0
5.43	6.334	1.988	8.322	13.361	1.262	14.623	.3502	.0628	.4130
5.93	6.402		6.402	13.506		13.506	.2019	.1942	.3961
6.27	6.436	2.020	8.456	13.578	1.282	14.860	.2307	.1900	.4207
6.92	7.451		7.451	14.665		14.665	.2867	.0366	.3233
7.03	7.451		7.451	14.665		14.665	0	0	0
7.17	8.587	8.968	17.555	15.795	4.233	20.028	0	.3094	.3094
7.52	8.605	6.282	14.887	15.792	3.149	18.941	.3868	.2348	.6216
7.86	8.617	6.291	14.908	15.815	3.154	18.969	.1713	.2038	.3751
8.48	20.326		20.326	24.306		24.306	.3831	.1596	.5427
9.10	64.268		64.268	43.227		43.227	.2714	0	.2714
9.52	62.861		62.861	27.599		27.599	.9970	"	.9970
10.27	"		"	"		"	1.0150	"	1.0150
11.02	"		"	"		"	.9636	"	.9636
11.77	"		"	"		"	"	"	"
12.52	"		"	"		"	"		"
13.27	"		"	"		"	"		"
14.02	"		"	"		"	"		"
14.77	"		"	"		"	"		"

DATA TOTALS
(cont.)

Station	EI X 106			AG/K X 10^6			Weight		
	Shaft	Comp.	Total	Shaft	Comp.	Total	Shaft	Comp.	Total
15.52	62.861		62.861	27.599		27.599	.9636	0	.9636
15.89	20.650		20.650	13.514		13.514	.2129	0	.2129
16.48	19.138		19.138	11.790		11.790	0	0	0
16.53	5.716	6.302	12.018	4.471	3.155	7.626	.2287	.1596	.3883
16.78	7.225	6.302	13.577	6.495	3.155	9.650	.1591	.2038	.3629
17.49	7.225	9.015	16.240	6.495	4.255	10.750	.2439	.2348	.4787
17.85	4.985		4.985	4.929		4.929	.0883	.3094	.3977
17.96	4.985		4.985	4.929		4.929	0	0	0
18.22							0	0	0

APPENDIX E

COMPUTER INPUT AND OUTPUT DATA

SIMPLE BEAM BENDING MODES, PROGRAM NO. 46
8/30/63 SN8TA DRW L910697/22/63RUN 1
BOUNDARY CONDITION--FREE-FREE

X	WEIGHT	EI	I-Z	AG/K	KS
0.	0.	1.5260000E 06	-0.	1.3270000E 06	-0.
4.1999999E-01	3.4960000E-01	4.4880000E 06	-0.	5.3009999E 06	-0.
5.2999999E-01	0.	2.3740000E 06	-0.	3.1470000E 06	-0.
7.7999999E-01	1.1001000E 00	2.3760000E 06	-1.9816000E 00	3.1510000E 06	-0.
1.1800000E 00	1.3570000E-01	2.3910000E 06	-0.	3.1690000E 06	-0.
1.5700000E 00	1.1637000E 00	2.4490000E 06	-2.2186000E 00	3.2470000E 06	-0.
2.1700000E 00	2.6840000E-01	2.3760000E 06	-0.	3.4290000E 06	-0.
2.7600000E 00	1.1486000E 00	2.6480000E 06	-2.0837000E 00	3.5110000E 06	-0.
3.1600000E 00	1.3800000E-01	2.6970000E 06	-0.	3.5750000E 06	-0.
3.5600000E 00	1.3039000E 00	2.7430000E 06	-2.6048000E 00	3.6370000E 06	-0.
4.2300000E 00	4.8820000E-01	4.7539999E 06	-0.	4.6680000E 06	-0.
4.3800000E 00	0.	6.7020000E 06	-0.	5.9169999E 06	-0.
4.6700000E 00	2.0620000E-01	6.6740000E 06	-0.	5.8130000E 06	-0.
4.9299999E 00	0.	8.1629999E 06	-0.	1.1302000E 07	-0.
5.2100000E 00	0.	8.2149999E 06	-0.	1.2746000E 07	-0.
5.4299999E 00	4.1299999E-01	8.3219999E 06	-0.	1.4623000E 07	-0.
5.9299999E 00	3.9610000E-01	6.4020000E 06	-0.	1.3506000E 07	-0.
6.2700000E 00	4.2070000E-01	8.4560000E 06	-0.	1.4860000E 07	-0.
6.9200000E 00	3.2330000E-01	7.4510000E 06	-0.	1.4665000E 07	-0.
7.0300000E 00	0.	7.4510000E 06	-0.	1.4665000E 07	1.0000000E 05
7.1700000E 00	3.0940000E-01	1.7555000E 07	-0.	2.0028000E 07	-0.
7.5200000E 00	6.2159999E-01	1.4887000E 07	-0.	1.8941000E 07	-0.
7.8600000E 00	3.7510000E-01	1.4908000E 07	-0.	1.8969000E 07	-0.
8.4799999E 00	5.4269999E-01	2.0326000E 07	-0.	2.4306000E 07	-0.
9.0999999E 00	2.7140000E-01	6.4268000E 07	-0.	4.3227000E 07	-0.
9.5200000E 00	9.9699999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.0270000E 01	1.0150000E 00	6.2861000E 07	-0.	2.7599000E 07	-0.
1.1020000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.1770000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.2520000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.3270000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.4020000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.4770000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.5520000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.5890000E 01	2.1290000E-01	2.0650000E 07	-0.	1.3514000E 07	-0.
1.6480000E 01	0.	1.9138000E 07	-0.	1.1790000E 07	-0.
1.6530000E 01	3.8830000E-01	1.2018000E 07	-0.	7.6259999E 06	-0.

1.6780000E 01	3.6289999E-01	1.3577000E 07	-0.	9.6499999E 06	-0.	
1.7490000E 01	4.7869999E-01	1.6240000E 07	-0.	1.0750000E 07	-0.	
1.7850000E 01	3.9770000E-01	4.9850000E 06	-0.	4.9290000E 06	-0.	
1.7960000E 01	0.	4.9850000E 06	-0.	4.9290000E 06		1.0000000E 05
1.8220000E 01	0.	0.	-0.	0.	-0.	

CENTER OF GRAVITY = 0.88471909E 01

OMEGA	RESIDUAL
0.09999999E 04	-0.20079241E 06
0.10100000E 04	-0.19424328E 06
0.10300000E 04	-0.18100187E 06
0.10600000E 04	-0.16078722E 06
0.11000000E 04	-0.13319068E 06
0.11499999E 04	-0.97689354E 05
0.12100000E 04	-0.53659422E 05
0.12800000E 04	-0.38288558E 03
0.13500000E 04	0.54905013E 05
0.13150000E 04	0.27010950E 05
0.12975000E 04	0.13251460E 05
0.12887499E 04	0.64186271E 04
0.12843750E 04	0.30139530E 04
0.12821875E 04	0.13145538E 04
0.12810937E 04	0.46558916E 03
0.12805469E 04	0.41290534E 02
0.12802734E 04	-0.17081283E 03
0.12804101E 04	-0.64764979E 02
0.12804785E 04	-0.11738179E 02
0.12805127E 04	0.14775938E 02
0.12804956E 04	0.15188197E 01
0.12804870E 04	-0.51096947E 01
0.12804913E 04	-0.17954412E 01
0.12804934E 04	-0.13831168E-00
0.12804934E 04	-0.13831168E-00

MODE 1
DEFLECTION NORMALIZED TO UNITY
OMEGA = 1.2804935E 03RADIANS/SEC
OMEGA = 2.0379704E 02CYCLES/SEC

X	SHEAR	MOMENT	BENDING ANGLE	TOTAL ANGLE	DEFLECTION
0.	0.	0.	-1.0034371E-01	-1.0034371E-01	1.0000000E 00
4.1999999E-01	0.	0.	-1.0034371E-01	-1.0034371E-01	9.5785563E-01
5.2999999E-01	1.4224562E 03	1.5647018E 02	-1.0034179E-01	-1.0061013E-01	9.4678838E-01
7.7999999E-01	1.4224562E 03	5.1208423E 02	-1.0030659E-01	-1.0075860E-01	9.2159355E-01
1.1800000E 00	5.7291007E 03	1.9593932E 03	-1.0016963E-01	-1.0198781E-01	8.8075817E-01
1.5700000E 00	6.2367969E 03	4.3917440E 03	-9.9651655E-02	-1.0161972E-01	8.4101257E-01
2.1700000E 00	1.0394093E 04	9.6890584E 03	-9.8041815E-02	-1.0124295E-01	7.7970746E-01
2.7600000E 00	1.1283052E 04	1.6346059E 04	-9.4809340E-02	-9.8099818E-02	7.2079371E-01
3.1600000E 00	1.4799848E 04	2.1426821E 04	-9.2019786E-02	-9.6235065E-02	6.8171197E-01
3.5600000E 00	1.5199468E 04	2.7506608E 04	-8.8391056E-02	-9.2642655E-02	6.4389910E-01
4.2300000E 00	1.8765864E 04	3.9101711E 04	-8.0375689E-02	-8.5535399E-02	5.8373377E-01
4.3800000E 00	1.9976407E 04	4.2098173E 04	-7.9094665E-02	-8.3374100E-02	5.7113039E-01
4.6700000E 00	1.9976407E 04	4.7891330E 04	-7.7147713E-02	-8.0523815E-02	5.4749013E-01
4.9299999E 00	2.0455955E 04	5.3209879E 04	-7.5178405E-02	-7.8697405E-02	5.2676830E-01
5.2100000E 00	2.0455955E 04	5.8937547E 04	-7.3255014E-02	-7.5064955E-02	5.0547625E-01
5.4299999E 00	2.0455955E 04	6.3437856E 04	-7.1616390E-02	-7.3221282E-02	4.8918511E-01
5.9299999E 00	2.1314159E 04	7.4094936E 04	-6.7484787E-02	-6.8942365E-02	4.5365435E-01
6.2700000E 00	2.2077463E 04	8.1601274E 04	-6.3350399E-02	-6.4985039E-02	4.3084530E-01
6.9200000E 00	2.2847411E 04	9.6452091E 04	-5.6507052E-02	-5.8044562E-02	3.9083041E-01
7.0300000E 00	2.3384148E 04	9.9024347E 04	-5.5064131E-02	-5.6658685E-02	3.8451824E-01
7.1700000E 00	-1.5067677E 04	9.6914873E 04	-5.3223338E-02	-5.4817893E-02	3.7708243E-01
7.5200000E 00	-1.4572085E 04	9.1814642E 04	-5.1341956E-02	-5.0614370E-02	3.5904112E-01
7.8600000E 00	-1.3624054E 04	8.7182465E 04	-4.9297924E-02	-4.8578635E-02	3.4217990E-01
8.4799999E 00	-1.3078837E 04	7.9073587E 04	-4.5840762E-02	-4.5151277E-02	3.1313181E-01
9.0999999E 00	-1.2356975E 04	7.1412262E 04	-4.3545642E-02	-4.3037249E-02	2.8574930E-01
9.5200000E 00	-1.2027545E 04	6.6360692E 04	-4.3095459E-02	-4.2817217E-02	2.6767269E-01
1.0270000E 01	-1.0893927E 04	5.8190246E 04	-4.2352445E-02	-4.1957723E-02	2.3593186E-01
1.1020000E 01	-9.8766954E 03	5.0782725E 04	-4.1702362E-02	-4.1344498E-02	2.0468523E-01
1.1770000E 01	-9.0388753E 03	4.4003568E 04	-4.1136910E-02	-4.0809403E-02	1.7387118E-01
1.2520000E 01	-8.3271838E 03	3.7758180E 04	-4.0649157E-02	-4.0347437E-02	1.4343236E-01
1.3270000E 01	-7.7400848E 03	3.1953117E 04	-4.0233291E-02	-3.9952843E-02	1.1331610E-01
1.4020000E 01	-7.2762580E 03	2.6495923E 04	-3.9884611E-02	-3.9620969E-02	8.3473690E-02
1.4770000E 01	-6.9345825E 03	2.1294987E 04	-3.9599513E-02	-3.9348250E-02	5.3859468E-02
1.5520000E 01	-6.7141243E 03	1.6259393E 04	-3.9375480E-02	-3.9132206E-02	2.4430057E-02
1.5890000E 01	-6.6141269E 03	1.3812166E 04	-3.9286980E-02	-3.9047329E-02	9.9666164E-03
1.6480000E 01	-6.6051134E 03	9.9151508E 03	-3.8948018E-02	-3.8459257E-02	-1.2818857E-02

1.6530000E 01	-6.6051134E 03	9.5848938E 03	-3.8922545E-02	-3.8362314E-02	-1.4737613E-02
1.6780000E 01	-6.6294222E 03	7.9275383E 03	-3.8740397E-02	-3.7871079E-02	-2.4227433E-02
1.7490000E 01	-6.6667697E 03	3.1941331E 03	-3.8449597E-02	-3.7758740E-02	-5.1124719E-02
1.7850000E 01	-6.7707286E 03	7.5666995E 02	-3.8405808E-02	-3.7775972E-02	-6.4730335E-02
1.7960000E 01	-6.8800817E 03	-1.3831169E-01	-3.8397461E-02	-3.7001623E-02	-6.8800816E-02
1.8220000E 01	-2.9103830E-11	-1.3831169E-01	-3.8397467E-02	-3.7001630E-02	-7.8784156E-02

MODE 1
DEFLECTION NORMALIZED TO TOTAL MASS
OMEGA = 1.2804935E 03RADIANS/SEC
OMEGA = 2.0379704E 02CYCLES/SEC

X	SHEAR	MOMENT	BENDING ANGLE	TOTAL ANGLE	DEFLECTION
0.	0.	0.	-2.1480672E-01	-2.1480672E-01	2.1407094E 00
4.1999999E-01	0.	0.	-2.1480672E-01	-2.1480672E-01	2.0504905E 00
5.2999999E-01	3.0450654E 03	3.3495718E 02	-2.1480262E-01	-2.1537705E-01	2.0267988E 00
7.7999999E-01	3.0450654E 03	1.0962235E 03	-2.1472726E-01	-2.1569487E-01	1.9728640E 00
1.1800000E 00	1.2264339E 04	4.1944913E 03	-2.1443406E-01	-2.1832626E-01	1.8854473E 00
1.5700000E 00	1.3351170E 04	9.4014475E 03	-2.1332523E-01	-2.1753828E-01	1.8003635E 00
2.1700000E 00	2.2250732E 04	2.0741458E 04	-2.0987903E-01	-2.1673174E-01	1.6691271E 00
2.7600000E 00	2.4153735E 04	3.4992162E 04	-2.0295924E-01	-2.1000320E-01	1.5430099E 00
3.1600000E 00	3.1682174E 04	4.5868596E 04	-1.9698762E-01	-2.0601130E-01	1.4593472E 00
3.5600000E 00	3.2537645E 04	5.8883654E 04	-1.8921956E-01	-1.9832100E-01	1.3784008E 00
4.2300000E 00	4.0172261E 04	8.3705399E 04	-1.7206099E-01	-1.8310643E-01	1.2496044E 00
4.3800000E 00	4.2763680E 04	9.0119953E 04	-1.6931869E-01	-1.7847972E-01	1.2226242E 00
4.6700000E 00	4.2763680E 04	1.0252142E 05	-1.6515083E-01	-1.7237809E-01	1.1720172E 00
4.9299999E 00	4.3790254E 04	1.1390688E 05	-1.6093511E-01	-1.6846827E-01	1.1276578E 00
5.2100000E 00	4.3790254E 04	1.2616816E 05	-1.5681769E-01	-1.6069225E-01	1.0820777E 00
5.4299999E 00	4.3790254E 04	1.3580201E 05	-1.5330988E-01	-1.5674548E-01	1.0472032E 00
5.9299999E 00	4.5627420E 04	1.5861572E 05	-1.4446532E-01	-1.4758557E-01	9.7114211E-01
6.2700000E 00	4.7261432E 04	1.7468461E 05	-1.3561479E-01	-1.3911408E-01	9.2231456E-01
6.9200000E 00	4.8909667E 04	2.0647589E 05	-1.2096518E-01	-1.2425654E-01	8.3665431E-01
7.0300000E 00	5.0058664E 04	2.1198235E 05	-1.1787630E-01	-1.2128978E-01	8.2314180E-01
7.1700000E 00	-3.2255516E 04	2.0746658E 05	-1.1393570E-01	-1.1734918E-01	8.0722388E-01
7.5200000E 00	-3.1194598E 04	1.9654846E 05	-1.0990821E-01	-1.0835066E-01	7.6860269E-01
7.8600000E 00	-2.9165139E 04	1.8663232E 05	-1.0553253E-01	-1.0399274E-01	7.3250771E-01
8.4799999E 00	-2.7997989E 04	1.6927357E 05	-9.8131748E-02	-9.6655760E-02	6.7032419E-01
9.0999999E 00	-2.6452691E 04	1.5287289E 05	-9.3218563E-02	-9.2130243E-02	6.1170621E-01
9.5200000E 00	-2.5747479E 04	1.4205895E 05	-9.2254852E-02	-9.1659218E-02	5.7300942E-01
1.0270000E 01	-2.3320732E 04	1.2456840E 05	-9.0664276E-02	-8.9819291E-02	5.0506154E-01
1.1020000E 01	-2.1143134E 04	1.0871105E 05	-8.9272636E-02	-8.8506553E-02	4.3817158E-01
1.1770000E 01	-1.9349605E 04	9.4198850E 04	-8.8062170E-02	-8.7361071E-02	3.7220767E-01
1.2520000E 01	-1.7826080E 04	8.0829290E 04	-8.7018031E-02	-8.6372136E-02	3.0704699E-01
1.3270000E 01	-1.6569272E 04	6.8402336E 04	-8.6127783E-02	-8.5527425E-02	2.4257684E-01
1.4020000E 01	-1.5576354E 04	5.6720071E 04	-8.5381360E-02	-8.4816979E-02	1.7869291E-01
1.4770000E 01	-1.4844926E 04	4.5586377E 04	-8.4771047E-02	-8.4233167E-02	1.1529747E-01
1.5520000E 01	-1.4372989E 04	3.4806635E 04	-8.4291458E-02	-8.3770679E-02	5.2297651E-02
1.5890000E 01	-1.4158923E 04	2.9567834E 04	-8.4102005E-02	-8.3588982E-02	2.1335629E-02
1.6480000E 01	-1.4139628E 04	2.1225456E 04	-8.3376386E-02	-8.2330091E-02	-2.7441447E-02

1.6530000E 01	-1.4139628E 04	2.0518472E 04	-8.3321856E-02	-8.2122564E-02	-3.1548946E-02
1.6780000E 01	-1.4191666E 04	1.6970555E 04	-8.2931931E-02	-8.1070971E-02	-5.1863893E-02
1.7490000E 01	-1.4271616E 04	6.8377107E 03	-8.2309412E-02	-8.0830487E-02	-1.0944317E-01
1.7850000E 01	-1.4494162E 04	1.6198104E 03	-8.2215672E-02	-8.0867378E-02	-1.3856883E-01
1.7960000E 01	-1.4728255E 04	-2.9608513E-01	-8.2197802E-02	-7.9209721E-02	-1.4728255E-01
1.8220000E 01	-6.2302842E-11	-2.9608513E-01	-8.2197818E-02	-7.9209736E-02	-1.6865398E-01

TOTAL WEIGHT = 2.0573398E 01 LBS.

MODE	GEN. MASS	GEN. STIFF.	SUM(M*Y)
1	1.1630632E-02	1.9070323E 04	1.9255012E-02

ORTHOGONALITY MATRIX

ROWB 1
1.0000000

SIMPLE BEAM BENDING MODES, PROGRAM NO. 46
8/30/63 SN8TA DRW L910697/22/63RUN 2
BOUNDARY CONDITION--FREE-FREE

X	WEIGHT	EI	I-Z	AG/K	KS
0.	0.	1.5260000E 06	-0.	1.3270000E 06	-0.
4.1999999E-01	3.4960000E-01	4.4880000E 06	-0.	5.3009999E 06	-0.
5.2999999E-01	0.	2.3740000E 06	-0.	3.1470000E 06	-0.
7.7999999E-01	1.1001000E 00	2.3760000E 06	-1.9816000E 00	3.1510000E 06	-0.
1.1800000E 00	1.3570000E-01	2.3910000E 06	-0.	3.1690000E 06	-0.
1.5700000E 00	1.1637000E 00	2.4490000E 06	-2.2186000E 00	3.2470000E 06	-0.
2.1700000E 00	2.6840000E-01	2.3760000E 06	-0.	3.4290000E 06	-0.
2.7600000E 00	1.1486000E 00	2.6480000E 06	-2.0837000E 00	3.5110000E 06	-0.
3.1600000E 00	1.3800000E-01	2.6970000E 06	-0.	3.5750000E 06	-0.
3.5600000E 00	1.3039000E 00	2.7430000E 06	-2.6048000E 00	3.6370000E 06	-0.
4.2300000E 00	4.8820000E-01	4.7539999E 06	-0.	4.6680000E 06	-0.
4.3800000E 00	0.	6.7020000E 06	-0.	5.9169999E 06	-0.
4.6700000E 00	2.0620000E-01	6.6740000E 06	-0.	5.8130000E 06	-0.
4.9299999E 00	0.	8.1629999E 06	-0.	1.1302000E 07	-0.
5.2100000E 00	0.	8.2149999E 06	-0.	1.2746000E 07	-0.
5.4299999E 00	4.1299999E-01	8.3219999E 06	-0.	1.4623000E 07	-0.
5.9299999E 00	3.9610000E-01	6.4020000E 06	-0.	1.3506000E 07	-0.
6.2700000E 00	4.2070000E-01	8.4560000E 06	-0.	1.4860000E 07	-0.
6.9200000E 00	3.2330000E-01	7.4510000E 06	-0.	1.4665000E 07	-0.
7.0300000E 00	0.	7.4510000E 06	-0.	1.4665000E 07	5.9999999E 05
7.1700000E 00	3.0940000E-01	1.7555000E 07	-0.	2.0028000E 07	-0.
7.5200000E 00	6.2159999E-01	1.4887000E 07	-0.	1.8941000E 07	-0.
7.8600000E 00	3.7510000E-01	1.4908000E 07	-0.	1.8969000E 07	-0.
8.4799999E 00	5.4269999E-01	2.0326000E 07	-0.	2.4306000E 07	-0.
9.0999999E 00	2.7140000E-01	6.4268000E 07	-0.	4.3227000E 07	-0.
9.5200000E 00	9.9699999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.0270000E 01	1.0150000E 00	6.2861000E 07	-0.	2.7599000E 07	-0.
1.1020000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.1770000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.2520000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.3270000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.4020000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.4770000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.5520000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.5890000E 01	2.1290000E-01	2.0650000E 07	-0.	1.3514000E 07	-0.
1.6480000E 01	0.	1.9138000E 07	-0.	1.1790000E 07	-0.
1.6530000E 01	3.8830000E-01	1.2018000E 07	-0.	7.6259999E 06	-0.

1.6780000E 01	3.6289999E-01	1.3577000E 07	-0.	9.6499999E 06	-0.	
1.7490000E 01	4.7869999E-01	1.6240000E 07	-0.	1.0750000E 07	-0.	
1.7850000E 01	3.9770000E-01	4.9850000E 06	-0.	4.9290000E 06	-0.	
1.7960000E 01	0.	4.9850000E 06	-0.	4.9290000E 06		5.9999999E 05
1.8220000E 01	0.	0.	-0.	0.	-0.	

CENTER OF GRAVITY = 0.88471909E 01

OMEGA	RESIDUAL
0.09999999E 04	-0.84780484E 07
0.10100000E 04	-0.83900989E 07
0.10300000E 04	-0.82139651E 07
0.10600000E 04	-0.79493786E 07
0.11000000E 04	-0.75964195E 07
0.11499999E 04	-0.71560404E 07
0.12100000E 04	-0.66306666E 07
0.12800000E 04	-0.60247938E 07
0.13600000E 04	-0.53454883E 07
0.14500000E 04	-0.46026966E 07
0.15499999E 04	-0.38092918E 07
0.16599999E 04	-0.29808209E 07
0.17800000E 04	-0.21349668E 07
0.19100000E 04	-0.12907900E 07
0.20500000E 04	-0.46785758E 06
0.21900000E 04	0.26561603E 06
0.21200000E 04	-0.90009435E 05
0.21550000E 04	0.90566697E 05
0.21375000E 04	0.97150110E 03
0.21287499E 04	-0.44345514E 05
0.21331250E 04	-0.21643672E 05
0.21353125E 04	-0.10325255E 05
0.21364062E 04	-0.46741702E 04
0.21369531E 04	-0.18506578E 04
0.21372265E 04	-0.43940921E 03
0.21373633E 04	0.26608823E 03
0.21372949E 04	-0.86649913E 02
0.21373291E 04	0.89721806E 02
0.21373120E 04	0.15366071E 01
0.21373120E 04	0.15366071E 01

MODE 1
DEFLECTION NORMALIZED TO UNITY
OMEGA = 2.1373120E 03RADIANS/SEC
OMEGA = 3.4016406E 02CYCLES/SEC

X	SHEAR	MOMENT	BENDING ANGLE	TOTAL ANGLE	DEFLECTION
0.	0.	0.	-1.5413389E-01	-1.5413389E-01	1.0000000E 00
4.1999999E-01	0.	0.	-1.5413389E-01	-1.5413389E-01	9.3526375E-01
5.2999999E-01	3.8694931E 03	4.2564422E 02	-1.5412867E-01	-1.5485862E-01	9.1822892E-01
7.7999999E-01	3.8694931E 03	1.3930175E 03	-1.5403291E-01	-1.5526249E-01	8.7939922E-01
1.1800000E 00	1.5318473E 04	3.9081545E 03	-1.5389075E-01	-1.5875221E-01	8.1583551E-01
1.5700000E 00	1.6628653E 04	1.0393329E 04	-1.5272437E-01	-1.5797166E-01	7.5396474E-01
2.1700000E 00	2.7012078E 04	2.2590654E 04	-1.4917508E-01	-1.5749417E-01	6.5820492E-01
2.7600000E 00	2.9102780E 04	3.9761294E 04	-1.4143357E-01	-1.4992082E-01	5.6725825E-01
3.1600000E 00	3.6813557E 04	5.0999040E 04	-1.3484198E-01	-1.4532719E-01	5.0773491E-01
3.5600000E 00	3.7642767E 04	6.6056146E 04	-1.2616158E-01	-1.3669103E-01	4.5124798E-01
4.2300000E 00	4.4605955E 04	9.2053027E 04	-1.0732684E-01	-1.1959133E-01	3.6440458E-01
4.3800000E 00	4.6711334E 04	9.9059730E 04	-1.0431180E-01	-1.1431851E-01	3.4702790E-01
4.6700000E 00	4.6711334E 04	1.1260601E 05	-9.9732344E-02	-1.0762677E-01	3.1513796E-01
4.9299999E 00	4.7480354E 04	1.2495091E 05	-9.5105075E-02	-1.0327303E-01	2.8767500E-01
5.2100000E 00	4.7480354E 04	1.3824541E 05	-9.0591111E-02	-9.4792168E-02	2.6049060E-01
5.4299999E 00	4.7480354E 04	1.4869108E 05	-8.6748991E-02	-9.0474110E-02	2.4015853E-01
5.9299999E 00	4.8654161E 04	1.7301816E 05	-7.7084571E-02	-8.0411805E-02	1.9747562E-01
6.2700000E 00	4.9579854E 04	1.8987532E 05	-6.7448224E-02	-7.1119173E-02	1.7163156E-01
6.9200000E 00	5.0434366E 04	2.2265765E 05	-5.1592830E-02	-5.4986798E-02	1.3060064E-01
7.0300000E 00	5.0934054E 04	2.2826040E 05	-4.8264351E-02	-5.1737522E-02	1.2472569E-01
7.1700000E 00	-2.3901359E 04	2.2491421E 05	-4.4006906E-02	-4.7480077E-02	1.1849561E-01
7.5200000E 00	-2.3467478E 04	2.1670059E 05	-3.9604594E-02	-3.8432860E-02	1.0427848E-01
7.8600000E 00	-2.2700374E 04	2.0898246E 05	-3.4743567E-02	-3.3545088E-02	9.2051771E-02
8.4799999E 00	-2.2291746E 04	1.9516158E 05	-2.6339713E-02	-2.5164546E-02	7.3874257E-02
9.0999999E 00	-2.1817284E 04	1.8163487E 05	-2.0593039E-02	-1.9695430E-02	5.9902940E-02
9.5200000E 00	-2.1624883E 04	1.7255241E 05	-1.9435708E-02	-1.8935445E-02	5.1709089E-02
1.0270000E 01	-2.1014770E 04	1.5679134E 05	-1.7470994E-02	-1.6709561E-02	3.8451903E-02
1.1020000E 01	-2.0552887E 04	1.4137667E 05	-1.5692260E-02	-1.4947563E-02	2.6585700E-02
1.1770000E 01	-2.0249712E 04	1.2618939E 05	-1.4096083E-02	-1.3362371E-02	1.5976680E-02
1.2520000E 01	-2.0067518E 04	1.1113875E 05	-1.2680292E-02	-1.1953181E-02	6.4920958E-03
1.3270000E 01	-1.9993485E 04	9.6143636E 04	-1.1443740E-02	-1.0719312E-02	-1.9999133E-03
1.4020000E 01	-2.0016291E 04	8.1131417E 04	-1.0386198E-02	-9.6609435E-03	-9.6310047E-03
1.4770000E 01	-2.0126120E 04	6.6036827E 04	-9.5082593E-03	-8.7790256E-03	-1.6533245E-02
1.5520000E 01	-2.0314660E 04	5.0800833E 04	-8.8112593E-03	-8.0751941E-03	-2.2839654E-02
1.5890000E 01	-2.0575116E 04	4.3188039E 04	-8.5346498E-03	-7.7891476E-03	-2.5771430E-02
1.6480000E 01	-2.0640049E 04	3.1010415E 04	-7.4746723E-03	-5.9473637E-03	-2.9575960E-02

1.6530000E 01	-2.0640049E 04	2.9978408E 04	-7.3950022E-03	-5.6443619E-03	-2.9860160E-02
1.6780000E 01	-2.0777266E 04	2.4784092E 04	-6.8254139E-03	-4.1008839E-03	-3.0954328E-02
1.7490000E 01	-2.0910206E 04	9.9378495E 03	-5.9175340E-03	-3.7506733E-03	-3.3893667E-02
1.7850000E 01	-2.1102219E 04	2.3410478E 03	-5.7814378E-03	-3.8184406E-03	-3.5287752E-02
1.7960000E 01	-2.1268303E 04	1.5366072E 00	-5.7555918E-03	-1.4406592E-03	-3.5447172E-02
1.8220000E 01	-1.7462298E-10	1.5366072E 00	-5.7555116E-03	-1.4405790E-03	-3.6943616E-02

MODE 1
DEFLECTION NORMALIZED TO TOTAL MASS
OMEGA = 2.1373120E 03RADIANS/SEC
OMEGA = 3.4016406E 02CYCLES/SEC

X	SHEAR	MOMENT	BENDING ANGLE	TOTAL ANGLE	DEFLECTION
0.	0.	0.	-4.2689376E-01	-4.2689376E-01	2.7696295E 00
4.1999999E-01	0.	0.	-4.2689376E-01	-4.2689376E-01	2.5903341E 00
5.2999999E-01	1.0717062E 04	1.1788768E 03	-4.2687932E-01	-4.2890102E-01	2.5431540E 00
7.7999999E-01	1.0717062E 04	3.8581424E 03	-4.2661409E-01	-4.3001958E-01	2.4356100E 00
1.1800000E 00	4.2426494E 04	1.0824140E 04	-4.2622035E-01	-4.3968480E-01	2.2595621E 00
1.5700000E 00	4.6055208E 04	2.8785671E 04	-4.2298994E-01	-4.3752298E-01	2.0882030E 00
2.1700000E 00	7.4813447E 04	6.2567741E 04	-4.1315972E-01	-4.3620050E-01	1.8229838E 00
2.7600000E 00	8.0603919E 04	1.1012405E 05	-3.9171860E-01	-4.1522514E-01	1.5710952E 00
3.1600000E 00	1.0195992E 05	1.4124845E 05	-3.7346234E-01	-4.0250248E-01	1.4062376E 00
3.5600000E 00	1.0425652E 05	1.8295105E 05	-3.4942085E-01	-3.7858351E-01	1.2497897E 00
4.2300000E 00	1.2354197E 05	2.5495278E 05	-2.9725557E-01	-3.3122367E-01	1.0092657E 00
4.3800000E 00	1.2937309E 05	2.7435875E 05	-2.8890505E-01	-3.1661993E-01	9.6113873E-01
4.6700000E 00	1.2937309E 05	3.1187694E 05	-2.7622165E-01	-2.9808629E-01	8.7281538E-01
4.9299999E 00	1.3150299E 05	3.4606772E 05	-2.6340582E-01	-2.8602805E-01	7.9675318E-01
5.2100000E 00	1.3150299E 05	3.8288856E 05	-2.5090382E-01	-2.6253919E-01	7.2146244E-01
5.4299999E 00	1.3150299E 05	4.1181921E 05	-2.4026257E-01	-2.5057977E-01	6.6515017E-01
5.9299999E 00	1.3475400E 05	4.7919621E 05	-2.1349570E-01	-2.2271091E-01	5.4693432E-01
6.2700000E 00	1.3731783E 05	5.2588428E 05	-1.8680659E-01	-1.9697376E-01	4.7535583E-01
6.9200000E 00	1.3968451E 05	6.1667920E 05	-1.4289303E-01	-1.5229306E-01	3.6171539E-01
7.0300000E 00	1.4106846E 05	6.3219674E 05	-1.3367437E-01	-1.4329377E-01	3.4544395E-01
7.1700000E 00	-6.6197910E 04	6.2292902E 05	-1.2188283E-01	-1.3150222E-01	3.2818894E-01
7.5200000E 00	-6.4996220E 04	6.0018036E 05	-1.0969005E-01	-1.0644478E-01	2.8881276E-01
7.8600000E 00	-6.2871626E 04	5.7880400E 05	-9.6226807E-02	-9.2907466E-02	2.5494930E-01
8.4799999E 00	-6.1739879E 04	5.4052528E 05	-7.2951248E-02	-6.9696470E-02	2.0460432E-01
9.0999999E 00	-6.0425794E 04	5.0306129E 05	-5.7035089E-02	-5.4549044E-02	1.6590895E-01
9.5200000E 00	-5.9892916E 04	4.7790626E 05	-5.3829711E-02	-5.2444167E-02	1.4321502E-01
1.0270000E 01	-5.8203127E 04	4.3425391E 05	-4.8388180E-02	-4.6279294E-02	1.0649753E-01
1.1020000E 01	-5.6923882E 04	3.9156100E 05	-4.3461746E-02	-4.1399212E-02	7.3632540E-02
1.1770000E 01	-5.6084199E 04	3.4949785E 05	-3.9040928E-02	-3.7008817E-02	4.4249485E-02
1.2520000E 01	-5.5579591E 04	3.0781316E 05	-3.5119710E-02	-3.3105884E-02	1.7980700E-02
1.3270000E 01	-5.5374545E 04	2.6628225E 05	-3.1694919E-02	-2.9688523E-02	-5.5390190E-03
1.4020000E 01	-5.5437710E 04	2.2470397E 05	-2.8765920E-02	-2.6757234E-02	-2.6674315E-02
1.4770000E 01	-5.5741896E 04	1.8289755E 05	-2.6334356E-02	-2.4314649E-02	-4.5790964E-02
1.5520000E 01	-5.6264082E 04	1.4069948E 05	-2.4403924E-02	-2.2365296E-02	-6.3257380E-02
1.5890000E 01	-5.6985449E 04	1.1961487E 05	-2.3637818E-02	-2.1573053E-02	-7.1377313E-02
1.6480000E 01	-5.7165288E 04	8.5887359E 04	-2.0702073E-02	-1.6471994E-02	-8.1914452E-02

1.6530000E 01	-5.7165288E 04	8.3029084E 04	-2.0481416E-02	-1.5632791E-02	-8.2701581E-02
1.6780000E 01	-5.7545329E 04	6.8642752E 04	-1.8903868E-02	-1.1357929E-02	-8.5732021E-02
1.7490000E 01	-5.7913525E 04	2.7524161E 04	-1.6389377E-02	-1.0387975E-02	-9.3872900E-02
1.7850000E 01	-5.8445330E 04	6.4838350E 03	-1.6012441E-02	-1.0575666E-02	-9.7733999E-02
1.7960000E 01	-5.8905321E 04	4.2558326E 00	-1.5940857E-02	-3.9900921E-03	-9.8175534E-02
1.8220000E 01	-4.8364096E-10	4.2558326E 00	-1.5940635E-02	-3.9898701E-03	-1.0232013E-01

TOTAL WEIGHT = 2.0573398E 01 LBS.

MODE	GEN. MASS	GEN. STIFF.	SUM(M*Y)
1	6.9482487E-03	3.1740313E 04	1.1726336E-02

ORTHOGONALITY MATRIX

ROWB 1
1.0000000

SIMPLE BEAM BENDING MODES, PROGRAM NO. 46
8/30/63 SN8TA DRW L910697/22/63RUN 3
BOUNDARY CONDITION--FREE-FREE

X	WEIGHT	EI	I-Z	AG/K	KS
0.	0.	1.5260000E 06	-0.	1.3270000E 06	-0.
4.1999999E-01	3.4960000E-01	4.4880000E 06	-0.	5.3009999E 06	-0.
5.2999999E-01	0.	2.3740000E 06	-0.	3.1470000E 06	-0.
7.7999999E-01	1.1001000E 00	2.3760000E 06	-1.9816000E 00	3.1510000E 06	-0.
1.1800000E 00	1.3570000E-01	2.3910000E 06	-0.	3.1690000E 06	-0.
1.5700000E 00	1.1637000E 00	2.4490000E 06	-2.2186000E 00	3.2470000E 06	-0.
2.1700000E 00	2.6840000E-01	2.3760000E 06	-0.	3.4290000E 06	-0.
2.7600000E 00	1.1486000E 00	2.6480000E 06	-2.0837000E 00	3.5110000E 06	-0.
3.1600000E 00	1.3800000E-01	2.6970000E 06	-0.	3.5750000E 06	-0.
3.5600000E 00	1.3039000E 00	2.7430000E 06	-2.6048000E 00	3.6370000E 06	-0.
4.2300000E 00	4.8820000E-01	4.7539999E 06	-0.	4.6680000E 06	-0.
4.3800000E 00	0.	6.7020000E 06	-0.	5.9169999E 06	-0.
4.6700000E 00	2.0620000E-01	6.6740000E 06	-0.	5.8130000E 06	-0.
4.9299999E 00	0.	8.1629999E 06	-0.	1.1302000E 07	-0.
5.2100000E 00	0.	8.2149999E 06	-0.	1.2746000E 07	-0.
5.4299999E 00	4.1299999E-01	8.3219999E 06	-0.	1.4623000E 07	-0.
5.9299999E 00	3.9610000E-01	6.4020000E 06	-0.	1.3506000E 07	-0.
6.2700000E 00	4.2070000E-01	8.4560000E 06	-0.	1.4860000E 07	-0.
6.9200000E 00	3.2330000E-01	7.4510000E 06	-0.	1.4665000E 07	-0.
7.0300000E 00	0.	7.4510000E 06	-0.	1.4665000E 07	1.0000000E 06
7.1700000E 00	3.0940000E-01	1.7555000E 07	-0.	2.0028000E 07	-0.
7.5200000E 00	6.2159999E-01	1.4887000E 07	-0.	1.8941000E 07	-0.
7.8600000E 00	3.7510000E-01	1.4908000E 07	-0.	1.8969000E 07	-0.
8.4799999E 00	5.4269999E-01	2.0326000E 07	-0.	2.4306000E 07	-0.
9.0999999E 00	2.7140000E-01	6.4268000E 07	-0.	4.3227000E 07	-0.
9.5200000E 00	9.9699999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.0270000E 01	1.0150000E 00	6.2861000E 07	-0.	2.7599000E 07	-0.
1.1020000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.1770000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.2520000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.3270000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.4020000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.4770000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.5520000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.5890000E 01	2.1290000E-01	2.0650000E 07	-0.	1.3514000E 07	-0.
1.6480000E 01	0.	1.9138000E 07	-0.	1.1790000E 07	-0.
1.6530000E 01	3.8830000E-01	1.2018000E 07	-0.	7.6259999E 06	-0.

1.6780000E 01	3.6289999E-01	1.3577000E 07	-0.	9.6499999E 06	-0.
1.7490000E 01	4.7869999E-01	1.6240000E 07	-0.	1.0750000E 07	-0.
1.7850000E 01	3.9770000E-01	4.9850000E 06	-0.	4.9290000E 06	-0.
1.7960000E 01	0.	4.9850000E 06	-0.	4.9290000E 06	1.0000000E 06
1.8220000E 01	0.	0.	-0.	0.	-0.

CENTER OF GRAVITY = 0.88471909E 01

OMEGA	RESIDUAL
0.09999999E 04	0.13312602E 08
0.10100000E 04	0.13284700E 08
0.10300000E 04	0.13227742E 08
0.10600000E 04	0.13139354E 08
0.11000000E 04	0.13015798E 08
0.11499999E 04	0.12851726E 08
0.12100000E 04	0.12639762E 08
0.12800000E 04	0.12369841E 08
0.13600000E 04	0.12028094E 08
0.14500000E 04	0.11594956E 08
0.15499999E 04	0.11041761E 08
0.16599999E 04	0.10324293E 08
0.17800000E 04	0.93695217E 07
0.19100000E 04	0.80454582E 07
0.20500000E 04	0.60824012E 07
0.22000000E 04	0.28205691E 07
0.23500000E 04	-0.33062513E 07
0.22750000E 04	0.32304738E 06
0.23125000E 04	-0.13044900E 07
0.22937500E 04	-0.45111219E 06
0.22843750E 04	-0.54869293E 05
0.22796874E 04	0.13629541E 06
0.22820313E 04	0.41274876E 05
0.22832031E 04	-0.66554491E 04
0.22826172E 04	0.17344989E 05
0.22829101E 04	0.53536092E 04
0.22830566E 04	-0.64870753E 03
0.22829834E 04	0.23530036E 04
0.22830200E 04	0.85228629E 03
0.22830383E 04	0.10182394E 03
0.22830474E 04	-0.27343315E 03
0.22830429E 04	-0.85802446E 02
0.22830406E 04	0.80112876E 01
0.22830406E 04	0.80112876E 01

MODE 1
DEFLECTION NORMALIZED TO UNITY
OMEGA = 2.2830406E 03RADIANS/SEC
OMEGA = 3.6335751E 02CYCLES/SEC

X	SHEAR	MOMENT	BENDING ANGLE	TOTAL ANGLE	DEFLECTION
0.	0.	0.	-1.6360894E-01	-1.6360894E-01	1.0000000E 00
4.1999999E-01	0.	0.	-1.6360894E-01	-1.6360894E-01	9.3128424E-01
5.2999999E-01	4.3963640E 03	4.8360002E 02	-1.6360301E-01	-1.6443236E-01	9.1319624E-01
7.7999999E-01	4.3963640E 03	1.5826910E 03	-1.6349421E-01	-1.6489121E-01	8.7195743E-01
1.1800000E 00	1.7349276E 04	4.1475999E 03	-1.6338012E-01	-1.6888607E-01	8.0434123E-01
1.5700000E 00	1.8823149E 04	1.1488628E 04	-1.6210489E-01	-1.6804466E-01	7.3851623E-01
2.1700000E 00	3.0428040E 04	2.4889045E 04	-1.5824357E-01	-1.6761469E-01	6.3656538E-01
2.7600000E 00	3.2735135E 04	4.4202775E 04	-1.4966525E-01	-1.5921180E-01	5.3986401E-01
3.1600000E 00	4.1108367E 04	5.6435016E 04	-1.4238227E-01	-1.5409071E-01	4.7668833E-01
3.5600000E 00	4.1996655E 04	7.3233678E 04	-1.3276649E-01	-1.4451381E-01	4.1687660E-01
4.2300000E 00	4.9336583E 04	1.0161934E 05	-1.1198218E-01	-1.2554737E-01	3.2534632E-01
4.3800000E 00	5.1481367E 04	1.0934155E 05	-1.0865402E-01	-1.1968260E-01	3.0714127E-01
4.6700000E 00	5.1481367E 04	1.2427114E 05	-1.0359974E-01	-1.1230032E-01	2.7382570E-01
4.9299999E 00	5.2243803E 04	1.3785453E 05	-9.8493904E-02	-1.0748131E-01	2.4520534E-01
5.2100000E 00	5.2243803E 04	1.5248279E 05	-9.3514456E-02	-9.8136982E-02	2.1701815E-01
5.4299999E 00	5.2243803E 04	1.6397643E 05	-8.9277023E-02	-9.3375862E-02	1.9600370E-01
5.9299999E 00	5.3336889E 04	1.9064487E 05	-7.8623896E-02	-8.2271361E-02	1.5213798E-01
6.2700000E 00	5.4150622E 04	2.0905609E 05	-6.8010155E-02	-7.2019529E-02	1.2581929E-01
6.9200000E 00	5.4865382E 04	2.4471858E 05	-5.0569667E-02	-5.4261819E-02	8.4732463E-02
7.0300000E 00	5.5235291E 04	2.5079446E 05	-4.6912008E-02	-5.0678478E-02	7.8955837E-02
7.1700000E 00	-2.3720547E 04	2.4747359E 05	-4.2230923E-02	-4.5997393E-02	7.2943010E-02
7.5200000E 00	-2.3415796E 04	2.3927806E 05	-3.7378657E-02	-3.6209503E-02	5.9425302E-02
7.8600000E 00	-2.2917001E 04	2.3148628E 05	-3.2002830E-02	-3.0792915E-02	4.8046863E-02
8.4799999E 00	-2.2673639E 04	2.1742862E 05	-2.2668002E-02	-2.1472702E-02	3.1870199E-02
9.0999999E 00	-2.2440087E 04	2.0351577E 05	-1.6248010E-02	-1.5324777E-02	2.0400565E-02
9.5200000E 00	-2.2365323E 04	1.9412234E 05	-1.4948701E-02	-1.4431308E-02	1.4068708E-02
1.0270000E 01	-2.2175919E 04	1.7749040E 05	-1.2731829E-02	-1.1928324E-02	4.3035406E-03
1.1020000E 01	-2.2116935E 04	1.6090269E 05	-1.0713130E-02	-9.9117628E-03	-3.8749242E-03
1.1770000E 01	-2.2167355E 04	1.4427718E 05	-8.8925664E-03	-8.0893724E-03	-1.0612267E-02
1.2520000E 01	-2.2305439E 04	1.2754810E 05	-7.2709811E-03	-6.4627837E-03	-1.6054975E-02
1.3270000E 01	-2.2514343E 04	1.1066234E 05	-5.8499265E-03	-5.0341598E-03	-2.0350899E-02
1.4020000E 01	-2.2779144E 04	9.3577983E 04	-4.6315220E-03	-3.8061608E-03	-2.3649681E-02
1.4770000E 01	-2.3086869E 04	7.6262831E 04	-3.6183294E-03	-2.7818183E-03	-2.6103080E-02
1.5520000E 01	-2.3426516E 04	5.8692943E 04	-2.8132448E-03	-1.9644273E-03	-2.7865206E-02
1.5890000E 01	-2.3789093E 04	4.9890980E 04	-2.4936822E-03	-1.6317274E-03	-2.8526467E-02
1.6480000E 01	-2.3871102E 04	3.5807034E 04	-1.2694253E-03	4.9697260E-04	-2.8574624E-02

1.6530000E 01	-2.3871102E 04	3.4613475E 04	-1.1774346E-03	8.4725598E-04	-2.8534548E-02
1.6780000E 01	-2.4020718E 04	2.8608295E 04	-5.1986084E-04	2.6299841E-03	-2.7956646E-02
1.7490000E 01	-2.4157715E 04	1.1456322E 04	5.2771482E-04	3.0311050E-03	-2.6123382E-02
1.7850000E 01	-2.4326578E 04	2.6987505E 03	6.8460608E-04	2.9475435E-03	-2.5084682E-02
1.7960000E 01	-2.4461289E 04	8.0112877E 00	7.1447002E-04	5.6771985E-03	-2.4461289E-02
1.8220000E 01	5.8207661E-11	8.0112877E 00	7.1488786E-04	5.6776164E-03	-2.4275472E-02

MODE 1
DEFLECTION NORMALIZED TO TOTAL MASS
OMEGA = 2.2830406E 03RADIANS/SEC
OMEGA = 3.6335751E 02CYCLES/SEC

X	SHEAR	MOMENT	BENDING ANGLE	TOTAL ANGLE	DEFLECTION
0.	0.	0.	-4.7213361E-01	-4.7213361E-01	2.8857446E 00
4.1999999E-01	0.	0.	-4.7213361E-01	-4.7213361E-01	2.6874485E 00
5.2999999E-01	1.2686784E 04	1.3955462E 03	-4.7211651E-01	-4.7450979E-01	2.6352512E 00
7.7999999E-01	1.2686784E 04	4.5672421E 03	-4.7180255E-01	-4.7583393E-01	2.5162465E 00
1.1800000E 00	5.0065580E 04	1.1968914E 04	-4.7147329E-01	-4.8736208E-01	2.3211234E 00
1.5700000E 00	5.4318802E 04	3.3153247E 04	-4.6779331E-01	-4.8493398E-01	2.1311692E 00
2.1700000E 00	8.7807553E 04	7.1823428E 04	-4.5665053E-01	-4.8369319E-01	1.8369651E 00
2.7600000E 00	9.4465240E 04	1.2755792E 05	-4.3189568E-01	-4.5944459E-01	1.5579097E 00
3.1600000E 00	1.1862825E 05	1.6285704E 05	-4.1087885E-01	-4.4466645E-01	1.3756008E 00
3.5600000E 00	1.2119162E 05	2.1133369E 05	-3.8313020E-01	-4.1702995E-01	1.2029994E 00
4.2300000E 00	1.4237278E 05	2.9324746E 05	-3.2315198E-01	-3.6229765E-01	9.3886640E-01
4.3800000E 00	1.4856208E 05	3.1553178E 05	-3.1354777E-01	-3.4537340E-01	8.8633127E-01
4.6700000E 00	1.4856208E 05	3.5861477E 05	-2.9896238E-01	-3.2407005E-01	7.9019104E-01
4.9299999E 00	1.5076227E 05	3.9781296E 05	-2.8422825E-01	-3.1016361E-01	7.0759998E-01
5.2100000E 00	1.5076227E 05	4.4002640E 05	-2.6985884E-01	-2.8319827E-01	6.2625895E-01
5.4299999E 00	1.5076227E 05	4.7319410E 05	-2.5763069E-01	-2.6945889E-01	5.6561662E-01
5.9299999E 00	1.5391664E 05	5.5015242E 05	-2.2688848E-01	-2.3741414E-01	4.3903134E-01
6.2700000E 00	1.5626487E 05	6.0328247E 05	-1.9625994E-01	-2.0782997E-01	3.6308234E-01
6.9200000E 00	1.5832748E 05	7.0619533E 05	-1.4593114E-01	-1.5658575E-01	2.4451625E-01
7.0300000E 00	1.5939494E 05	7.2372878E 05	-1.3537607E-01	-1.4624514E-01	2.2784638E-01
7.1700000E 00	-6.8451439E 04	7.1414558E 05	-1.2186766E-01	-1.3273673E-01	2.1049490E-01
7.5200000E 00	-6.7572008E 04	6.9049538E 05	-1.0786526E-01	-1.0449138E-01	1.7148625E-01
7.8600000E 00	-6.6132612E 04	6.6801028E 05	-9.2351993E-02	-8.8860488E-02	1.3865098E-01
8.4799999E 00	-6.5430333E 04	6.2744349E 05	-6.5414065E-02	-6.1964735E-02	9.1969255E-02
9.0999999E 00	-6.4756359E 04	5.8729454E 05	-4.6887606E-02	-4.4223394E-02	5.8870822E-02
9.5200000E 00	-6.4540610E 04	5.6018748E 05	-4.3138131E-02	-4.1645069E-02	4.0598699E-02
1.0270000E 01	-6.3994039E 04	5.1219195E 05	-3.6740806E-02	-3.4422097E-02	1.2418919E-02
1.1020000E 01	-6.3823827E 04	4.6432408E 05	-3.0915358E-02	-2.8602816E-02	-1.1182041E-02
1.1770000E 01	-6.3969325E 04	4.1634709E 05	-2.5661676E-02	-2.3343863E-02	-3.0624293E-02
1.2520000E 01	-6.4367802E 04	3.6807124E 05	-2.0982195E-02	-1.8649943E-02	-4.6330557E-02
1.3270000E 01	-6.4970645E 04	3.1934326E 05	-1.6881394E-02	-1.4527300E-02	-5.8727496E-02
1.4020000E 01	-6.5734794E 04	2.7004216E 05	-1.3365390E-02	-1.0983608E-02	-6.8246940E-02
1.4770000E 01	-6.6622809E 04	2.2007505E 05	-1.0441574E-02	-8.0276171E-03	-7.5326824E-02
1.5520000E 01	-6.7602944E 04	1.6937284E 05	-8.1183063E-03	-5.6688355E-03	-8.0411868E-02
1.5890000E 01	-6.8649246E 04	1.4397262E 05	-7.1961302E-03	-4.7087485E-03	-8.2320098E-02
1.6480000E 01	-6.8885904E 04	1.0332996E 05	-3.6632374E-03	1.4341360E-03	-8.2459067E-02

1.6530000E 01	-6.8885904E 04	9.9885648E 04	-3.3977755E-03	2.4449644E-03	-8.2343417E-02
1.6780000E 01	-6.9317658E 04	8.2556233E 04	-1.5001856E-03	7.5894625E-03	-8.0675740E-02
1.7490000E 01	-6.9712997E 04	3.3060019E 04	1.5228502E-03	8.7469949E-03	-7.5385408E-02
1.7850000E 01	-7.0200291E 04	7.7879048E 03	1.9755983E-03	8.5058578E-03	-7.2387987E-02
1.7960000E 01	-7.0589033E 04	2.3118530E 01	2.0617780E-03	1.6382945E-02	-7.0589033E-02
1.8220000E 01	1.6797244E-10	2.3118530E 01	2.0629838E-03	1.6384151E-02	-7.0052814E-02

TOTAL WEIGHT = 2.0573398E 01 LBS.

MODE	GEN. MASS	GEN. STIFF.	SUM(M*Y)
1	6.4003382E-03	3.3360319E 04	1.0455042E-02

ORTHOGONALITY MATRIX

ROW8 1
1.0000000

SIMPLE BEAM BENDING MODES, PROGRAM NO. 46
8/30/63 SN8TA DRW L910697/22/63RUN 4
BOUNDARY CONDITION--FREE-FREE

X	WEIGHT	EI	I-Z	AG/K	KS
0.	0.	1.5260000E 06	-0.	1.3270000E 06	-0.
4.1999999E-01	3.4960000E-01	4.4880000E 06	-0.	5.3009999E 06	-0.
5.2999999E-01	0.	2.3740000E 06	-0.	3.1470000E 06	-0.
7.7999999E-01	1.1001000E 00	2.3760000E 06	-1.9816000E 00	3.1510000E 06	-0.
1.1800000E 00	1.3570000E-01	2.3910000E 06	-0.	3.1690000E 06	-0.
1.5700000E 00	1.1637000E 00	2.4490000E 06	-2.2186000E 00	3.2470000E 06	-0.
2.1700000E 00	2.6840000E-01	2.3760000E 06	-0.	3.4290000E 06	-0.
2.7600000E 00	1.1486000E 00	2.6480000E 06	-2.0837000E 00	3.5110000E 06	-0.
3.1600000E 00	1.3800000E-01	2.6970000E 06	-0.	3.5750000E 06	-0.
3.5600000E 00	1.3039000E 00	2.7430000E 06	-2.6048000E 00	3.6370000E 06	-0.
4.2300000E 00	4.8820000E-01	4.7539999E 06	-0.	4.6680000E 06	-0.
4.3800000E 00	0.	6.7020000E 06	-0.	5.9169999E 06	-0.
4.6700000E 00	2.0620000E-01	6.6740000E 06	-0.	5.8130000E 06	-0.
4.9299999E 00	0.	8.1629999E 06	-0.	1.1302000E 07	-0.
5.2100000E 00	0.	8.2149999E 06	-0.	1.2746000E 07	-0.
5.4299999E 00	4.1299999E-01	8.3219999E 06	-0.	1.4623000E 07	-0.
5.9299999E 00	3.9610000E-01	6.4020000E 06	-0.	1.3506000E 07	-0.
6.2700000E 00	4.2070000E-01	8.4560000E 06	-0.	1.4860000E 07	-0.
6.9200000E 00	3.2330000E-01	7.4510000E 06	-0.	1.4665000E 07	-0.
7.0300000E 00	0.	7.4510000E 06	-0.	1.4665000E 07	1.0000000E 07
7.1700000E 00	3.0940000E-01	1.7555000E 07	-0.	2.0028000E 07	-0.
7.5200000E 00	6.2159999E-01	1.4887000E 07	-0.	1.8941000E 07	-0.
7.8600000E 00	3.7510000E-01	1.4908000E 07	-0.	1.8969000E 07	-0.
8.4799999E 00	5.4269999E-01	2.0326000E 07	-0.	2.4306000E 07	-0.
9.0999999E 00	2.7140000E-01	6.4268000E 07	-0.	4.3227000E 07	-0.
9.5200000E 00	9.9699999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.0270000E 01	1.0150000E 00	6.2861000E 07	-0.	2.7599000E 07	-0.
1.1020000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.1770000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.2520000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.3270000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.4020000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.4770000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.5520000E 01	9.6359999E-01	6.2861000E 07	-0.	2.7599000E 07	-0.
1.5890000E 01	2.1290000E-01	2.0650000E 07	-0.	1.3514000E 07	-0.
1.6480000E 01	0.	1.9138000E 07	-0.	1.1790000E 07	-0.
1.6530000E 01	3.8830000E-01	1.2018000E 07	-0.	7.6259999E 06	-0.

1.678C000E 01	3.6289999E-01	1.3577000E 07	-0.	9.6499999E 06	-0.
1.749C000E 01	4.7869999E-01	1.6240000E 07	-0.	1.0750000E 07	-0.
1.785C000E 01	3.9770000E-01	4.9850000E 06	-0.	4.9290000E 06	-0.
1.796C000E 01	0.	4.9850000E 06	-0.	4.9290000E 06	1.0000000E 07
1.822000CE 01	0.	0.	-0.	0.	-0.

CENTER OF GRAVITY = 0.88471909E 01

OMEGA	RESIDUAL
0.09999999E 04	0.31750339E 07
0.10100000E 04	0.31610154E 07
0.10300000E 04	0.31326113E 07
0.10600000E 04	0.30890944E 07
0.11000000E 04	0.30293929E 07
0.11499999E 04	0.29521135E 07
0.12100000E 04	0.28555747E 07
0.12800000E 04	0.27378507E 07
0.13600000E 04	0.25968280E 07
0.14500000E 04	0.24302755E 07
0.15499999E 04	0.22359300E 07
0.16599999E 04	0.20115982E 07
0.17800000E 04	0.17552739E 07
0.19100000E 04	0.14652721E 07
0.20500000E 04	0.11403763E 07
0.22000000E 04	0.77999765E 06
0.23599999E 04	0.38433903E 06
0.25200000E 04	-0.19953363E 05
0.24400000E 04	0.18308122E 06
0.24800000E 04	0.81762195E 05
0.25000000E 04	0.30951004E 05
0.25099999E 04	0.55100957E 04
0.25150000E 04	-0.72188617E 04
0.25125000E 04	-0.85368410E 03
0.25112500E 04	0.23283812E 04
0.25118750E 04	0.73739235E 03
0.25121874E 04	-0.58134943E 02
0.25120312E 04	0.33963144E 03
0.25121094E 04	0.14074893E 03
0.25121484E 04	0.41307165E 02
0.25121679E 04	-0.84138460E 01
0.25121582E 04	0.16446669E 02
0.25121631E 04	0.40164145E 01
0.25121655E 04	-0.21987151E 01
0.25121655E 04	-0.21987151E 01

MODE 1
DEFLECTION NORMALIZED TO UNITY
OMEGA = 2.5121655E 03RADIANS/SEC
OMEGA = 3.9982390E 02CYCLES/SEC

X	SHEAR	MOMENT	BENDING ANGLE	TOTAL ANGLE	DEFLECTION
0.	0.	0.	-1.7824573E-01	-1.7824573E-01	1.0000000E 00
4.1999999E-01	0.	0.	-1.7824573E-01	-1.7824573E-01	9.2513678E-01
5.2999999E-01	5.2879406E 03	5.8167344E 02	-1.7823860E-01	-1.7923614E-01	9.0542028E-01
7.7999999E-01	5.2879406E 03	1.9036586E 03	-1.7810774E-01	-1.7978805E-01	8.6045401E-01
1.1800000E 00	2.0764308E 04	4.4389543E 03	-1.7805958E-01	-1.8464933E-01	7.8653804E-01
1.5700000E 00	2.2509362E 04	1.3217605E 04	-1.7661958E-01	-1.8372257E-01	7.1455891E-01
2.1700000E 00	3.6104645E 04	2.8473800E 04	-1.7229723E-01	-1.8341661E-01	6.0294686E-01
2.7600000E 00	3.8750529E 04	5.1336612E 04	-1.6238811E-01	-1.7368893E-01	4.9726807E-01
3.1600000E 00	4.8088845E 04	6.5039941E 04	-1.5401618E-01	-1.6771280E-01	4.2841171E-01
3.5600000E 00	4.9055452E 04	8.4662120E 04	-1.4291480E-01	-1.5663661E-01	3.6343979E-01
4.2300000E 00	5.6803386E 04	1.1663398E 05	-1.1907403E-01	-1.3469222E-01	2.6469031E-01
4.3800000E 00	5.8916121E 04	1.2547140E 05	-1.1525453E-01	-1.2787580E-01	2.4521899E-01
4.6700000E 00	5.8916121E 04	1.4255708E 05	-1.0945564E-01	-1.1941273E-01	2.0973059E-01
4.9299999E 00	5.9623187E 04	1.5805910E 05	-1.0360007E-01	-1.1385694E-01	1.7935348E-01
5.2100000E 00	5.9623187E 04	1.7475360E 05	-9.7892143E-02	-1.0316760E-01	1.4965408E-01
5.4299999E 00	5.9623187E 04	1.8787070E 05	-9.3036553E-02	-9.7714349E-02	1.2761637E-01
5.9299999E 00	6.0484906E 04	2.1811315E 05	-8.0840451E-02	-8.4976736E-02	8.2003267E-02
6.2700000E 00	6.1015968E 04	2.3885858E 05	-6.8705930E-02	-7.3223623E-02	5.5013148E-02
6.9200000E 00	6.1394365E 04	2.7876492E 05	-4.8811461E-02	-5.2942979E-02	1.3968351E-02
7.0300000E 00	6.1468199E 04	2.8552642E 05	-4.4646111E-02	-4.8837600E-02	8.3662050E-03
7.1700000E 00	-2.2193850E 04	2.8241928E 05	-3.9310425E-02	-4.3501915E-02	2.7018037E-03
7.5200000E 00	-2.2180183E 04	2.7465622E 05	-3.3757122E-02	-3.2649664E-02	-9.6928931E-03
7.8600000E 00	-2.2278692E 04	2.6708146E 05	-2.7570826E-02	-2.6394611E-02	-1.9713829E-02
8.4799999E 00	-2.2399592E 04	2.5319372E 05	-1.6752118E-02	-1.5571266E-02	-3.2691971E-02
9.0999999E 00	-2.2689667E 04	2.3912612E 05	-9.2435505E-03	-8.3100498E-03	-4.0149688E-02
9.5200000E 00	-2.2867823E 04	2.2952164E 05	-7.7122124E-03	-7.1831952E-03	-4.3486015E-02
1.0270000E 01	-2.3576672E 04	2.1183913E 05	-5.0792556E-03	-4.2249974E-03	-4.7628936E-02
1.1020000E 01	-2.4367071E 04	1.9356383E 05	-2.6608069E-03	-1.7779100E-03	-4.9855658E-02
1.1770000E 01	-2.5152524E 04	1.7469943E 05	-4.6391653E-04	4.4743983E-04	-5.0329846E-02
1.2520000E 01	-2.5945448E 04	1.5524035E 05	1.5043535E-03	2.4444399E-03	-4.9220106E-02
1.3270000E 01	-2.6720889E 04	1.3519968E 05	3.2369860E-03	4.2051691E-03	-4.6701022E-02
1.4020000E 01	-2.7456642E 04	1.1460720E 05	4.7272196E-03	5.7220616E-03	-4.2952958E-02
1.4770000E 01	-2.8133347E 04	9.3507191E 04	5.9687350E-03	6.9880961E-03	-3.8161720E-02
1.5520000E 01	-2.8734568E 04	7.1956264E 04	6.9558144E-03	7.9969596E-03	-3.2518085E-02
1.5890000E 01	-2.9246876E 04	6.1134921E 04	7.3475019E-03	8.4072096E-03	-2.9477916E-02
1.6480000E 01	-2.9349484E 04	4.3818731E 04	8.8468392E-03	1.1018623E-02	-2.3394910E-02

1.6530000E 01	-2.9349484E 04	4.2351252E 04	8.9594036E-03	1.1448758E-02	-2.2825268E-02
1.6780000E 01	-2.9494392E 04	3.4977654E 04	9.7637067E-03	1.3631316E-02	-1.9514781E-02
1.7490000E 01	-2.9610179E 04	1.3954433E 04	1.1043141E-02	1.4111554E-02	-9.8847324E-03
1.7850000E 01	-2.9687542E 04	3.2669136E 03	1.1234019E-02	1.3995650E-02	-4.8735468E-03
1.7960000E 01	-2.9719232E 04	-2.1987152E 00	1.1270038E-02	1.7299503E-02	-2.9719231E-03
1.8220000E 01	1.1920929E-07	-2.1987152E 00	1.1269924E-02	1.7299388E-02	-4.1728180E-05

MODE 1
DEFLECTION NORMALIZED TO TOTAL MASS
OMEGA = 2.5121655E 03RADIANS/SEC
OMEGA = 3.9982390E 02CYCLES/SEC

X	SHEAR	MOMENT	BENDING ANGLE	TOTAL ANGLE	DEFLECTION
0.	0.	0.	-5.4455642E-01	-5.4455642E-01	3.0550881E 00
4.1999999E-01	0.	0.	-5.4455642E-01	-5.4455642E-01	2.8263744E 00
5.2999999E-01	1.6155124E 04	1.7770636E 03	-5.4453464E-01	-5.4758219E-01	2.7661387E 00
7.7999999E-01	1.6155124E 04	5.8158447E 03	-5.4413484E-01	-5.4926834E-01	2.6287628E 00
1.1800000E 00	6.3436790E 04	1.3561396E 04	-5.4398770E-01	-5.6411997E-01	2.4029430E 00
1.5700000E 00	6.8768082E 04	4.0380949E 04	-5.3958838E-01	-5.6128863E-01	2.1830404E 00
2.1700000E 00	1.1030287E 05	8.6989968E 04	-5.2638321E-01	-5.6035391E-01	1.8420558E 00
2.7600000E 00	1.1838628E 05	1.5683787E 05	-4.9610997E-01	-5.3063499E-01	1.5191978E 00
3.1600000E 00	1.4691566E 05	1.9870275E 05	-4.7053300E-01	-5.1237738E-01	1.3088355E 00
3.5600000E 00	1.4986873E 05	2.5865024E 05	-4.3661731E-01	-4.7853863E-01	1.1103406E 00
4.2300000E 00	1.7353935E 05	3.5632710E 05	-3.6378164E-01	-4.1149661E-01	8.0865221E-01
4.3800000E 00	1.7999394E 05	3.8332619E 05	-3.5211273E-01	-3.9067184E-01	7.4916560E-01
4.6700000E 00	1.7999394E 05	4.3552443E 05	-3.3439662E-01	-3.6481642E-01	6.4074544E-01
4.9299999E 00	1.8215408E 05	4.8288449E 05	-3.1650733E-01	-3.4784297E-01	5.4794068E-01
5.2100000E 00	1.8215408E 05	5.3388764E 05	-2.9906912E-01	-3.1518610E-01	4.5720639E-01
5.4299999E 00	1.8215408E 05	5.7396153E 05	-2.8423487E-01	-2.9852594E-01	3.8987925E-01
5.9299999E 00	1.8478671E 05	6.6635489E 05	-2.4697470E-01	-2.5961141E-01	2.5052721E-01
6.2700000E 00	1.8640915E 05	7.2973401E 05	-2.0990267E-01	-2.2370462E-01	1.6807001E-01
6.9200000E 00	1.8756519E 05	8.5165137E 05	-1.4912331E-01	-1.6174547E-01	4.2674543E-02
7.0300000E 00	1.8779076E 05	8.7230836E 05	-1.3639780E-01	-1.4920317E-01	2.5559493E-02
7.1700000E 00	-6.7804168E 04	8.6281577E 05	-1.2009681E-01	-1.3290218E-01	8.2542481E-03
7.5200000E 00	-6.7762413E 04	8.3909894E 05	-1.0313098E-01	-9.9747598E-02	-2.9612643E-02
7.8600000E 00	-6.8063365E 04	8.1595739E 05	-8.4231303E-02	-8.0637861E-02	-6.0227484E-02
8.4799999E 00	-6.8432726E 04	7.7352911E 05	-5.1179197E-02	-4.7571589E-02	-9.9876851E-02
9.0999999E 00	-6.9318931E 04	7.3055137E 05	-2.8239861E-02	-2.5387934E-02	-1.2266083E-01
9.5200000E 00	-6.9863214E 04	7.0120882E 05	-2.3561488E-02	-2.1945294E-02	-1.3285361E-01
1.0270000E 01	-7.2028810E 04	6.4718721E 05	-1.5517574E-02	-1.2907739E-02	-1.4551059E-01
1.1020000E 01	-7.4443549E 04	5.9135454E 05	-8.1289994E-03	-5.4316717E-03	-1.5231343E-01
1.1770000E 01	-7.6843178E 04	5.3372216E 05	-1.4173059E-03	1.3669681E-03	-1.5376211E-01
1.2520000E 01	-7.9265631E 04	4.7427294E 05	4.5959323E-03	7.4679794E-03	-1.5037176E-01
1.3270000E 01	-8.1634668E 04	4.1304694E 05	9.8892772E-03	1.2847162E-02	-1.4267574E-01
1.4020000E 01	-8.3882462E 04	3.5013509E 05	1.4442073E-02	1.7481402E-02	-1.3122507E-01
1.4770000E 01	-8.5949854E 04	2.8567270E 05	1.8235011E-02	2.1349249E-02	-1.1658742E-01
1.5520000E 01	-8.7786635E 04	2.1983272E 05	2.1250626E-02	2.4431416E-02	-9.9345614E-02
1.5890000E 01	-8.9351780E 04	1.8677257E 05	2.2447266E-02	2.5684766E-02	-9.0057629E-02
1.6480000E 01	-8.9665258E 04	1.3387008E 05	2.7027873E-02	3.3662863E-02	-7.1473511E-02

1.6530000E 01	-8.9665258E 04	1.2938680E 05	2.7371767E-02	3.4976963E-02	-6.9733203E-02
1.6780000E 01	-9.0107964E 04	1.0685981E 05	2.9828984E-02	4.1644872E-02	-5.9619375E-02
1.7490000E 01	-9.0461704E 04	4.2632021E 04	3.3737770E-02	4.3112040E-02	-3.0198728E-02
1.7850000E 01	-9.0698057E 04	9.9807088E 03	3.4320916E-02	4.2757944E-02	-1.4889115E-02
1.7960000E 01	-9.0794871E 04	-6.7172686E 00	3.4430960E-02	5.2851506E-02	-9.0794870E-03
1.8220000E 01	3.6419488E-07	-6.7172685E 00	3.4430609E-02	5.2851155E-02	-1.2748327E-04

TOTAL WEIGHT = 2.0573398E 01 LBS.

MODE	GEN. MASS	GEN. STIFF.	SUM(M*Y)
1	5.7104619E-03	3.6038586E 04	8.5474608E-03

ORTHOGONALITY MATRIX

ROWB 1
1.0000000

APPENDIX F

CALCULATION OF TAA TORSIONAL, NATURAL FREQUENCY

01-071-002

QUADRILLE WORK SHEET

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

PAGE 1 OF ___ PAGES
DATE OCT. 14, 1963
SUBJECT ___ BY CSM WORK ORDER ___

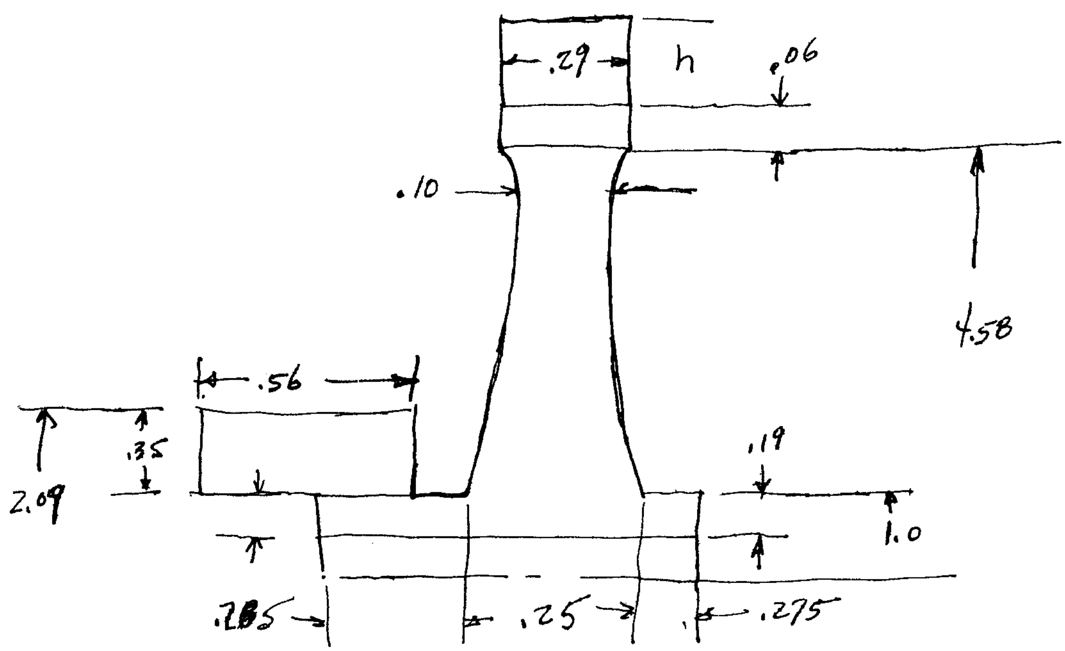
TAA TORSIONAL VIBRATION - NATURAL FREQUENCY

FROM GE REPORT 3-9-11-63, THE MOMENT OF INERTIA OF THE ALTERNATOR ROTOR IS

$$J = .0621 \text{ lb-ft-sec}^2$$

MOMENT OF INERTIA, TURBINE DISKS

THE FIRST STAGE DISK IS ASSUMED TO BE THE FOLLOWING SHAPE



MOMENT OF BLADES - ~~00~~91791

$$I = \int r^2 dm = mr^2$$

$$m = \pi D \rho A = \frac{\pi D \rho \times .29 \times .32 \times .42}{32.2}$$

$$m = 3.14 \times 5.08 \times .283 \times .29 \times .0042 = .0052 \ \frac{lb\text{-}sec^2}{ft}$$

$$I = .0055 \times 2.54^2 = \frac{.0355}{144} = .000246 \ lb\text{-}ft\text{-}sec^2$$

MOMENT OF RIMS

$$r = 2.79 + .03 = 2.82$$

$$m = \frac{3.14 \times 2.82 \times 2 \times .283 \times .29 \times .06}{32.2} = .00271$$

$$I = mr^2 = \left(\frac{2.82}{12}\right)^2 \times .00271 = .0001495$$

MOMENT OF DISK

$$dm = \rho t 2\pi r dr$$

LET $t = K_1 r + K_2$

$$\frac{.10}{12} = K_1 \times \frac{2.75}{12} + K_2$$

$$\frac{.25}{12} = K_1 \frac{\times 1.5}{12} + K_2$$

$$-\frac{.15}{12} = \frac{1.25}{12} K_1$$

$$K_1 = \cancel{-.0857} \ -.12$$

$$K_2 = \frac{.1}{12} + \frac{.12 \times 2.75}{12} = .0358$$

$$I = 2\pi\rho \int r^3 (K_1 r + K_2) dr = 2\pi\rho \left[\tfrac{1}{5} K_1 r^5 + \tfrac{1}{4} K_2 r^4 \right]$$

$$I = 2\pi\rho \left[.0000116 \right] = 2 \times 3.14 \times \frac{.283 \times 1728}{32.2} \times 1.16 \times 10^{-5}$$

$$I = 1.107 \times 10^{-3}$$

MOMENT OF HUB

$$I = \frac{.60^2}{144} \times \frac{.81 \times 3.14 \times 1.19 \times .19 \times .283}{32.2}$$

$$I = .126 \times 10^{-5}$$

MOMENT OF SPLINE EXTENSION

$$I = \frac{.87^2}{12^2} \times 3.14 \times 1.74 \times .56 \times .35 \times \frac{.283}{32.2} = 4.96 \times 10^{-5}$$

THE TOTAL MOMENT IS THEN

$$I = I_{BLADES} + I_{RIM} + I_{DISK} + I_{HUB} + I_{SPLINE\ EXT.}$$

$$I_{WHEEL} = 2.46 + 1.495 + 12.6 + .126 + .496 = 1.72 \times 10^{-3} \text{ lb-ft-sec}^2$$

01-071-002

QUADRILLE WORK SHEET

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

PAGE 4 OF ____ PAGES

DATE

SUBJECT ____ BY ____ WORK ORDER ____

SECOND STAGE - 093074

MOMENT OF BLADES

$$m = \pi D \rho A = \frac{3.14 \times 5.15 \times .283 \times .29 \times .46 \times .42}{32.2} = .00796 \; \frac{lb\text{-}sec^2}{ft}$$

$$I = mr^2 = .00796 \times \left(\frac{5.14}{24}\right)^2 = .000\ 365\ lb\text{-}ft\text{-}sec^2$$

MOMENT OF DISK - SAME AS BEFORE (1ST STAGE)

MOMENT OF HUB

$$I = \frac{.60^2}{144} \times \frac{3.14 \times 1.19 \times 1.23 \times .19 \times .283}{32.2} = 1.91 \times 10^{-5}$$

MOMENT OF WHEEL

$$I = .365 + 1.26 + .019 = 1.64\ lb\text{-}ft\text{-}sec^2$$

THIRD STAGE - FOURTH STAGE - SAME AS SECOND STAGE

TOTAL WHEEL MOMENT OF INERTIA

$$I_{WHEELS} = 1.7 + 3 \times 1.6 = .0065\ lb\text{-}ft\text{-}sec^2$$

MOMENT OF INERTIA - SHAFT

$$I_1 = \frac{3 \times .15 \times 3.14 \times 1.4 \times .29}{32.2} \times \left(\frac{.7}{12}\right)^2 = .000061 \text{ lb-sec-ft}^2$$

(.0034, .0001)

$$I_2 = \frac{1}{2} \times (\pi R^2 - \pi r^2) L \times \rho \, [R^2 + r^2]$$

$$I_2 = \frac{3.14}{\cancel{2}} \times \cancel{8}^{4} \times \frac{.29}{32.2} \left[R^4 - r^4\right]$$

$$I_2 = .113 \left[1.23^4 - .47^4\right] = \frac{.113 \times 2.24}{144} = .00176 \text{ lb-sec-ft}^2$$

$$2.29 - .049$$

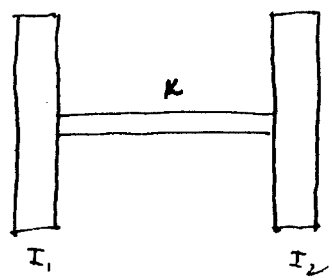
(.029, .0151, .0001)

$$I_3 = \frac{1}{2} \times \frac{3.14}{4} \times \cancel{1.52}^{\,2.25} \times 3.5 \times \frac{.29}{32.2} \times \frac{.75^2}{144} = .000109$$

$$I_{SHAFT} = \cancel{.00193} = .002$$

$$\text{TOTAL ROTOR} = .0065 + .002 = .0085 \text{ lb-sec}^2\text{-ft}^2$$

THE WEAKEST SPRING WITHIN THE SYSTEM IS THE QUILL SHAFT. THEREFOR THE FIRST MODE MAY BE APPROXIMATED BY THE FOLLOWING EQUIVALENT SYSTEM



$$K = 1.18\times10^6 \frac{D^4}{l} = 1.18\times10^6 \frac{\times \overset{.178}{\cancel{.65^4}}}{16} = 1.31\times10^4$$

THE NATURAL FREQUENCY IS

$$\omega_n = \sqrt{\frac{K(I_1+I_2)}{I_1 I_2}}$$

$$I_1 = .0621 \text{ lb-ft-sec}^2 = .745 \text{ lb-in-sec}^2$$

$$I_2 = .0085\times12 = .102 \text{ lb-in-sec}^2$$

$$\omega_n = \sqrt{\frac{1.31\times10^4(.847)}{.0759}} = \sqrt{1.463\times10^5} \approx 383 \text{ rad/sec.}$$

$$\omega_n = \frac{383}{2\pi}\times60 = 3650 \text{ Cycle/min} =$$

NATURAL FREQUENCY BASED ON TURBINE SHAFT

$$K = 1.18 \times 10^6 \frac{\left[\cancel{(2.46)^4 - (.99)^4}\right]^{4.5}}{12} = 4.42 \times 10^5$$

$$\omega_n = 21,200 \text{ cycles/min.}$$

NATURAL FREQUENCY OF ROTORS - TORSION

$$\frac{1}{\omega^2} = \frac{1}{\omega_{Q.S.}^2} + \frac{1}{\omega_S^2}$$

$$\omega^2 = \frac{\omega_{Q.S.}^2 \times \omega_S^2}{\omega_{Q.S}^2 + \omega_S^2}$$

$$\omega_{Q.S.}^2 = 3650^2 = 1.332 \times 10^7$$

$$\omega_S^2 = 4.49 \times 10^8$$

$$\omega^2 = \frac{5.99 \times 10^{15}}{4.62 \times 10^8} = 1.295 \times 10^7$$

$$\omega = \underline{\underline{3600 \text{ cycles/min.}}}$$

APPENDIX G

NATURAL FREQUENCY OF COMPOSITE TURBINE HOUSING IN THE LATERAL DIRECTION

(H. F. Hafen)

NATURAL FREQUENCY OF COMPOSITE TURBINE HOUSING

INTRODUCTION

THE OBJECTIVE OF THE ANALYSIS ON PAGES 2-5 IS TO DETERMINE THE NATURAL FREQUENCY OF LATERAL VIBRATION FOR THE TURBINE HOUSING.

A GRAPHICAL DESCRIPTION OF THE VIBRATING SYSTEM AND THE DIMENSIONS OF THE SUPPORTING ARMS ARE SHOWN IN FIGURES 1 AND 2, ON PAGES 2 AND 7.

THE STRAIN ENERGY DUE TO THE REACTION FORCES P IN THE SUPPORTING ARMS 2 AND 4, AND DUE TO THE BENDING MOMENTS IN THE ARMS 1 AND 3 IS CALCULATED.
THE DEFLECTION IN Y-DIRECTION IS DETERMINED BY USING THE CASTIGLIANO THEOREM.
FROM THE DEFLECTION THE FREQUENCY IS CALCULATED.

CONCLUSIONS

THE DEFLECTION IN Y-DIRECTION, MEASURED AT THE END OF AN ARM IS

$\delta_y = (3.58\,Q - 10.28\,P)\,10^{-6}$ INCH, WHERE

Q = WEIGHT OF THE TURBINE IN LB,

$P = 0.21\,Q$ = REACTION FORCE IN ARMS 2 AND 4

FOR $Q = 50$ LB

FREQUENCY $f = 22527 \frac{\text{CYCLES}}{\text{MINUTE}}$

WITHOUT ARMS 2 AND 4 $(P = 0)$

$\delta_y = 3.58\,Q = 3.58 \times 50$

$f = 14042 \frac{\text{CYCLES}}{\text{MINUTE}}$

H F Hafen
FEB 10, 1964

CALCULATIONS

STRAIN ENERGY IN CANTILEVERS 1 AND 3 DUE TO BENDING

$$U_B = \int_0^L \frac{M^2 dx}{2E(2I)}$$

STRAIN ENERGY IN CANTILEVERS 2 AND 4 DUE TO ELONGATION

$$U_E = 2\int_0^L \frac{P^2 dx}{2AE}$$

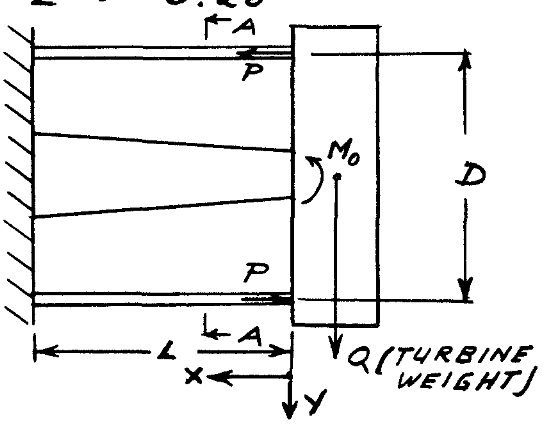
TOTAL STRAIN ENERGY

$$U = U_B + U_E$$

$$M = Qx + M_o$$
$$M_o = -PD$$
$$E = 30 \times 10^6$$
$$I = \frac{0.19}{12}\left(1.78 + 0.252x\right)^3$$
$$A = 0.19\left(1.78 + 0.252x\right)$$

$\Big\}$ FOR MINIMUM THICKNESS = 0.19" = CONSTANT

$$D = 9.575''$$
$$L = 6.26''$$



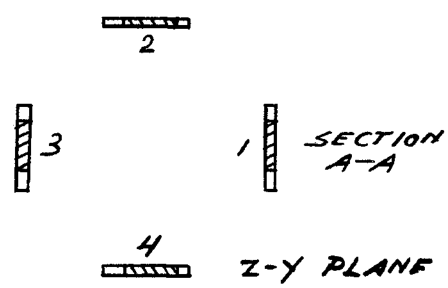


FIG 1

DEFLECTION IN Y-DIRECTION

$$\delta_y = \frac{\delta U}{\delta Q} = \frac{1}{2E}\int_0^L \frac{M \frac{\delta M}{\delta Q}\, dx}{I} + \frac{2P}{E}\int_0^L \frac{\frac{\delta P}{\delta Q}\, dx}{A}$$

$$\delta_y = \frac{1}{2E}\int_0^L \frac{M \frac{\delta M}{\delta Q}\, dx}{I} = \frac{12}{0.19}\,\frac{1}{2E}\int_0^L \frac{Qx^2dx - PDx\,dx}{(1.78 + 0.252x)^3}$$

$$\delta_y = \frac{12}{0.19}\,\frac{1}{2E}\left(3.3975\,Q - 0.9765\,DP\right)$$ SEE PAGE 5

$$\rightarrow \delta_y = (3.5763\,Q - 10.2789\,P)\,10^{-6} \text{ INCH}$$

OBTAIN P FROM $\frac{\delta U}{\delta P} = 0$

$$\frac{\delta U}{\delta P} = \frac{1}{2E}\int_0^L \frac{M \frac{\delta M}{\delta P}\, dx}{I} + \frac{2P}{E}\int_0^L \frac{\delta x}{A}$$

$$\frac{\delta U}{\delta P} = -\frac{12}{0.19}\,\frac{D}{2E}\int_0^L \frac{Qx\,dx - PD\,dx}{(1.78+0.252x)^3} + \frac{1}{0.19}\,\frac{2P}{E}\int_0^L \frac{dx}{1.78+0.252x}$$

$$\frac{\delta U}{\delta P} = -\frac{12}{0.19}\,\frac{D}{2E}\left(0.9765\,Q - 0.4502\,PD\right) + \frac{1}{0.19}\,\frac{2}{E}\,2.5183\,P$$

$$\frac{\delta U}{\delta P} = (-9.8420\,Q + 45.3752\,P + 0.8836\,P)\,10^{-6}$$

$$\rightarrow \frac{\delta U}{\delta P} = 0 \qquad P = 0.2128\,Q$$

SUBSTITUTING

$$\rightarrow \delta_y = 1.3890 \times 10^{-6} \times Q \text{ INCH}$$

FREQUENCY

$$f = \frac{30\sqrt{g}}{\pi}\sqrt{\frac{1}{\delta_Y}} = 187.74\sqrt{\frac{1}{\delta_Y}} \quad \frac{\text{CYCLES}}{\text{MINUTE}}$$

$Q = 50$ LB

WITHOUT CANTILEVERS 2 AND 4

$P = 0 \qquad \delta_Y = 3.5763\ 10^{-6}\ Q = 178.815\ 10^{-6}$ INCH

$f = 14042 \quad \frac{\text{CYCLES}}{\text{MINUTE}}$

WITH ALL CANTILEVERS PRESENT

$P = 0.2128\ Q = 10.64$ LB

$\delta_Y = 1.3890\ 10^{-6}\ Q = 69.45\ 10^{-6}$ INCH

$f = 22527 \quad \frac{\text{CYCLES}}{\text{MINUTE}}$ 26500

$$\int \frac{x^2\,dx}{(a+bx)^3} = \frac{1}{b^3}\left[\ln(a+bx) + \frac{2a}{a+bx} - \frac{a^2}{2(a+bx)^2}\right]$$

$$\int \frac{x\,dx}{(a+bx)^3} = \frac{1}{b^2}\left[-\frac{1}{a+bx} + \frac{a}{2(a+bx)^2}\right]$$

$$\int \frac{dx}{(a+bx)^3} = \frac{1}{b}\left[-\frac{1}{2(a+bx)^2}\right]$$

$$\int \frac{dx}{a+bx} = \frac{1}{b}\ln(a+bx)$$

$a = 1.78$ $a^2 = 3.1684$ $2a = 3.56$
$b = 0.252$ $b^2 = 0.063504$ $b^3 = 0.016003$
$L = 6.26$ $a+bL = 3.35752$ $(a+bL)^2 = 11.2729$
$\ln(a+bL) = 1.2105$ $\ln a = 0.5759$

$$\int_0^L \frac{x^2\,dx}{(a+bx)^3} = 3.3975$$

$$\int_0^L \frac{x\,dx}{(a+bx)^3} = 0.9765$$

$$\int_0^L \frac{dx}{(a+bx)^3} = 0.4502$$

$$\int_0^L \frac{dx}{a+bx} = 2.5183$$

M, M_0	MOMENT	LB IN.
P	FORCE	LB
Q	WEIGHT OF TURBINE	LB
L, D, x	LENGTH	IN.
U	STRAIN ENERGY	LB IN
E	MODULUS OF ELASTICITY	PSI
I	MOMENT OF INERTIA $\int y^2 dA$ OF ONE CANTILEVER, WITH RESPECT TO X-AXIS	$IN.^4$
A	AREA OF CROSS-SECTION OF ONE CANTILEVER, IN Y-Z PLANE	IN^2
δ	DEFLECTION	IN
f	FREQUENCY	CYCLES/MINUTE
g	ACCELERATION DUE TO GRAVITY = 386	IN/SEC^2

H. C. Hofer
FEB 10, 1964

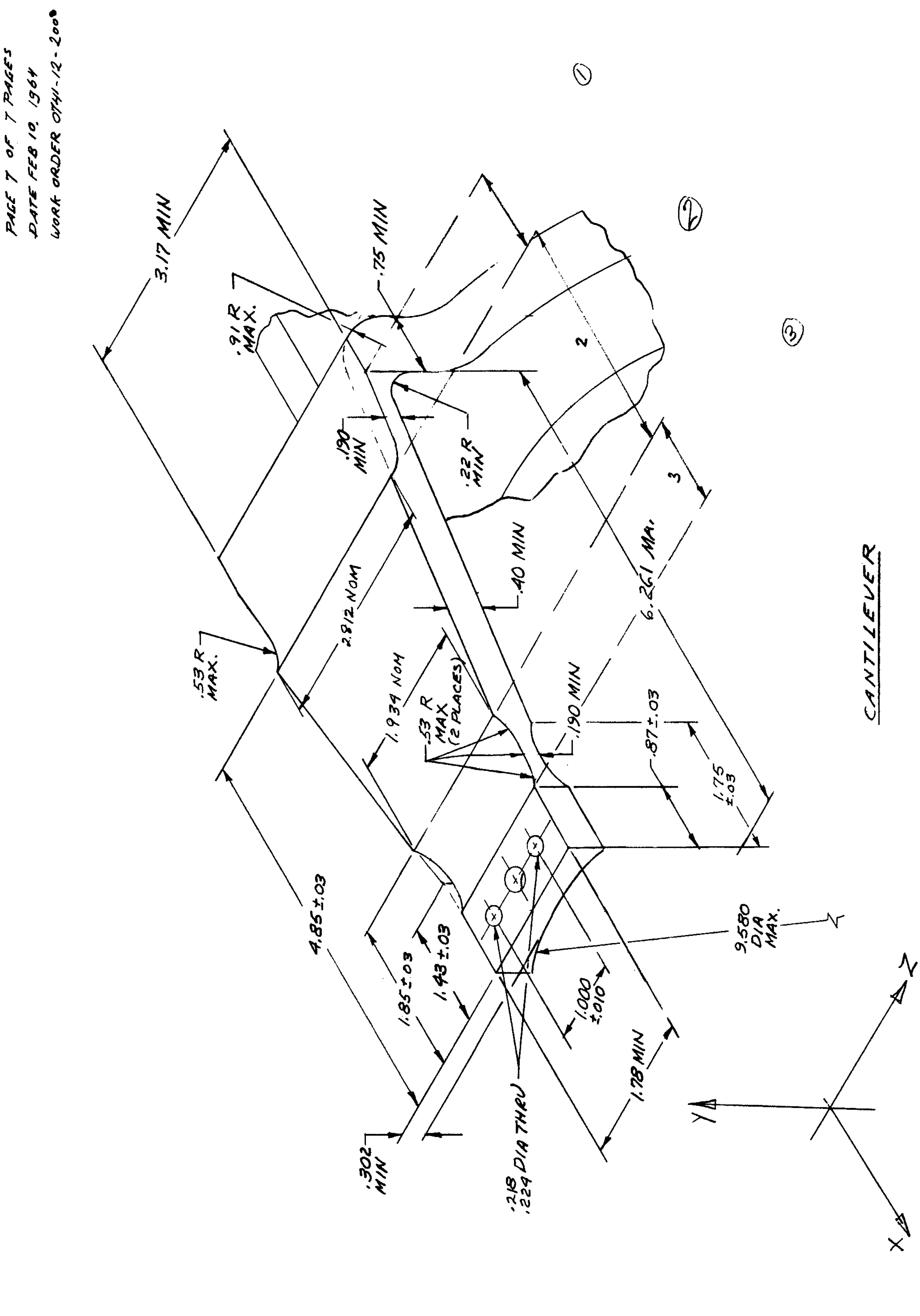


Figure 2
Page IV-223

QUADRILLE WORK SHEET

SUBJECT ______ BY H.F. HAFEN WORK ORDER ______

NATURAL FREQUENCY OF COMPOSITE TURBINE-HOUSING — SUPPLEMENT 1

THIS REPORT IS A SUPPLEMENT TO THE PREVIOUS REPORT DEALING WITH THE SUBJECT, DATED FEBRUARY 10, 1964.

IN ORDER TO CONSIDER THE EFFECT OF THE ARM-LENGTH ON THE FREQUENCY OF THE HOUSING, THE EQUATIONS ARE REWRITTEN AND THE FREQUENCY IS PLOTTED VERSUS THE ARMLENGTH (PAGE 2).

H F Hafen

APRIL 24, 1964

NATURAL FREQUENCY OF COMPOSITE TURBINE-HOUSE VERSUS ARM LENGTH

REFERRING TO FIG 1

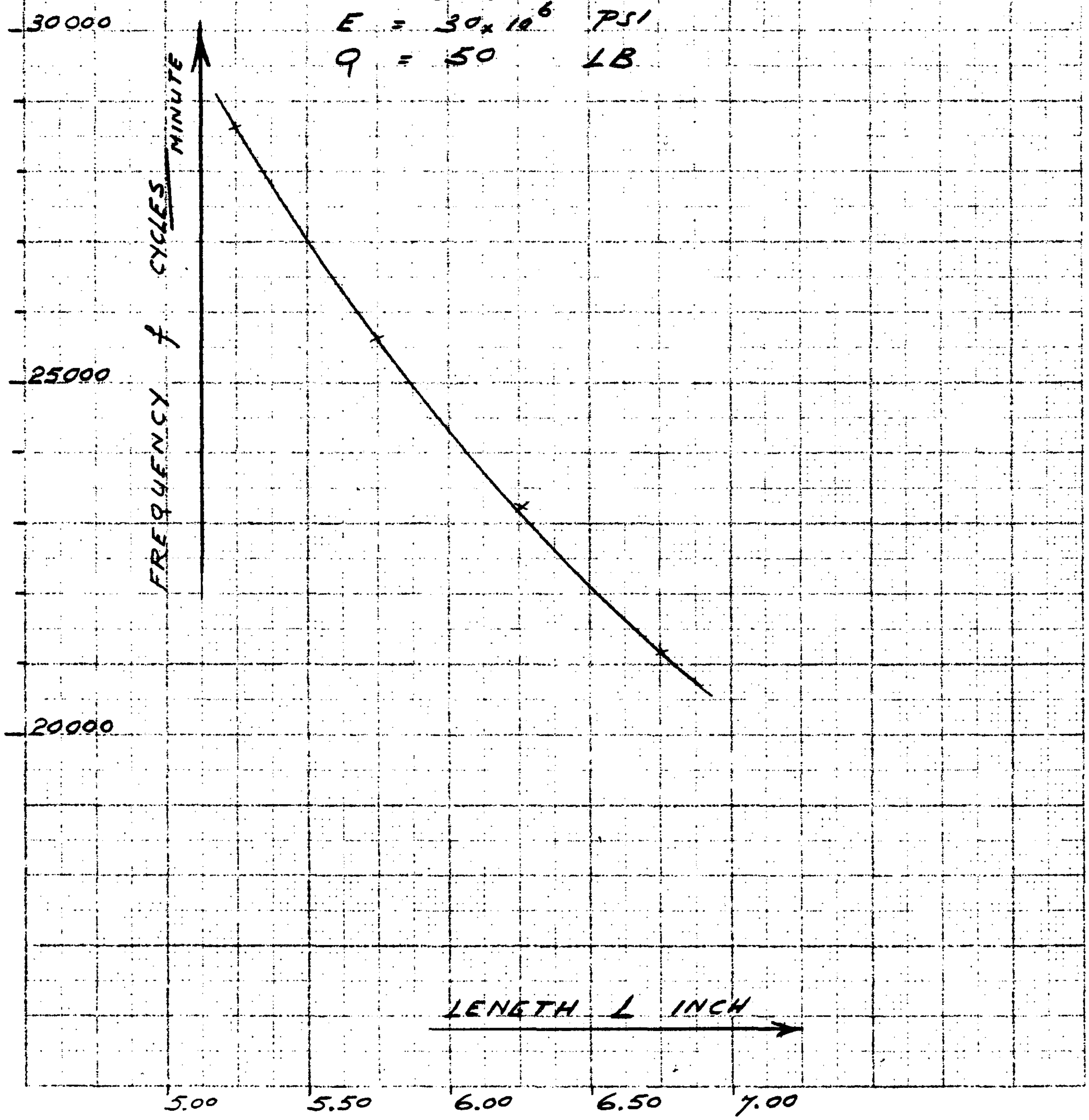
$a = 1.780$ INCH

$b = 0.252$ "

$D = 9.575$ "

$E = 30 \times 10^{6}$ PSI

$q = 50$ LB



CALCULATIONS

STRAIN ENERGY IN CANTILEVERS 1 AND 3 DUE TO BENDING

$$U_B = \int_0^L \frac{M^2 dx}{2E(2I)}$$

STRAIN ENERGY IN CANTILEVERS 2 AND 4 DUE TO ELONGATION

$$U_E = 2\int_0^L \frac{P^2 dx}{2AE}$$

TOTAL STRAIN ENERGY

$$U = U_B + U_E$$

$M = Qx + M_0$
$M_0 = -PD$
$E = 30 \times 10^6$
$I = \frac{0.19}{12}(1.78 + 0.252x)^3$
$A = 0.19(1.78 + 0.252x)$

} FOR MINIMUM THICKNESS = 0.19 = CONSTANT

$D = 9.575''$
$L = 6.26''$

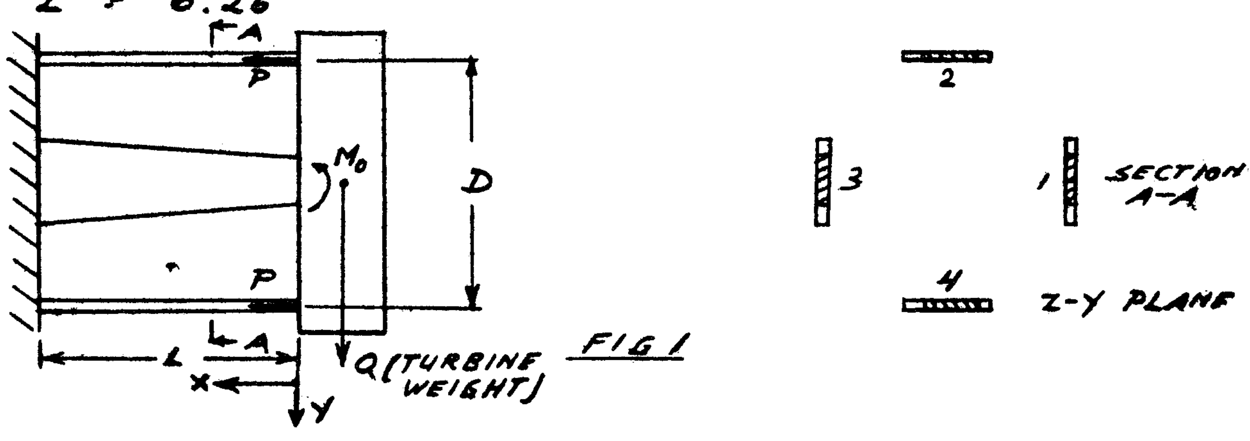


FIG 1

DEFLECTION IN Y-DIRECTION

$$\delta_y = \frac{\delta U}{\delta Q} = \frac{1}{2E}\int_0^L \frac{M\frac{\delta M}{\delta Q}dx}{I} + \frac{2P}{E}\int_0^L \frac{\frac{\delta P}{\delta Q}dx}{A} = \frac{1}{2E}\int_0^L \frac{M\frac{\delta M}{\delta Q}dx}{I} \tag{1}$$

$$M = Qx + M_0 \quad , \quad M_0 = -DP \quad , \quad I = \frac{0.19}{12}(a+bx)^3 ,$$

$$\delta_y = \frac{12}{0.19}\frac{1}{2E}\int_0^L \frac{Qx^2dx - DP\,x\,dx}{(a+bx)^3} \tag{1a}$$

THE INTEGRALS ARE EXPRESSED ON PAGE 6

$$\delta_y = \frac{31.58}{E}\left[\frac{Q}{b^3}\left\{\underset{IV}{\ln(1+\tfrac{b}{a}L) + \frac{2a}{a+bL} - \frac{0.50a^2}{(a+bL)^2} - 1.50}\right\} - \frac{DP}{b^2}\left\{\underset{I}{-\frac{1}{a+bL} + \frac{0.50a}{(a+bL)^2} + \frac{0.50}{a}}\right\}\right] \tag{1b}$$

$$\frac{\delta U}{\delta P} = \frac{1}{2E}\int_0^L \frac{M\frac{\delta M}{\delta P}dx}{I} + \frac{2P}{E}\int_0^L \frac{dx}{A} = 0 \tag{2}$$

$$A = 0.19(a+bx)$$

$$\frac{\delta U}{\delta P} = -\frac{12}{0.19}\frac{D}{2E}\int_0^L \frac{Qx\,dx - DP\,dx}{(a+bx)^3} + \frac{1}{0.19}\frac{2P}{E}\int_0^L \frac{dx}{a+bx} = 0 \tag{2a}$$

$$-\frac{31.58D}{E}\left[\frac{Q}{b^2}\left\{\underset{I}{-\frac{1}{a+bL} + \frac{0.50a}{(a+bL)^2} + \frac{0.50}{a}}\right\} - \frac{DP}{2b}\left\{\underset{II}{-\frac{1}{(a+bL)^2} + \frac{1}{a^2}}\right\}\right]$$

$$+ \frac{10.53P}{bE}\underset{III}{\ln(1+\tfrac{b}{a}L)} = 0 \tag{2b}$$

FROM (2b)

THE TENSILE FORCE IN ARM 2 OR 4

$$P = \frac{2D}{b} q \left[\frac{I}{D^2 II + 0.6669\, III} \right] \qquad LB \qquad (3)$$

(3) AND (1b)

THE DEFLECTION IN Y-DIRECTION

$$\delta_Y = \frac{31.58}{E b^3} q \left[IV - \frac{I^2}{0.50\, II + \frac{0.3334}{D^2} III} \right] \qquad INCH \qquad (4)$$

WHERE

$$I = -\frac{1}{a+bL} + \frac{0.50a}{(a+bL)^2} + \frac{0.50}{a}$$

$$II = -\frac{1}{(a+bL)^2} + \frac{1}{a^2}$$

$$III = \ln\left(1 + \frac{b}{a}L\right) = 2.3026 \log_{10}\left(1 + \frac{b}{a}L\right)$$

$$IV = \ln\left(1 + \frac{b}{a}L\right) + \frac{2a}{a+bL} - \frac{0.50a^2}{(a+bL)^2} - 1.50$$

THE FREQUENCY IN Y-DIRECTION

$$f = \frac{30\sqrt{g}}{\pi} \sqrt{\frac{1}{\delta_Y}} = 187.74 \sqrt{\frac{1}{\delta_Y}} \qquad \text{CYCLES/MINUTE} \qquad (5)$$

REFERRING TO FIG 1

$a = 1.78$ INCH, $b = 0.252$, $L = 6.26$, $D = 9.575$, $E = 30 \times 10^6$
$q = 50$ LB

$$\int_0^L \frac{x^2\,dx}{(a+bx)^3} = \frac{1}{b^3}\left[\ln\left(1+\frac{b}{a}L\right) + \frac{2a}{a+bL} - \frac{0.50\,a^2}{(a+bL)^2} - 1.50\right]$$

$$\int_0^L \frac{x\,dx}{(a+bx)^3} = \frac{1}{b^2}\left[-\frac{1}{a+bL} + \frac{0.50\,a}{(a+bL)^2} + \frac{1}{2a}\right]$$

$$\int_0^L \frac{dx}{(a+bx)^3} = \frac{1}{2b}\left[-\frac{1}{(a+bL)^2} + \frac{1}{a^2}\right]$$

$$\int_0^L \frac{dx}{a+bx} = \frac{1}{b}\ln\left(1+\frac{b}{a}L\right)$$

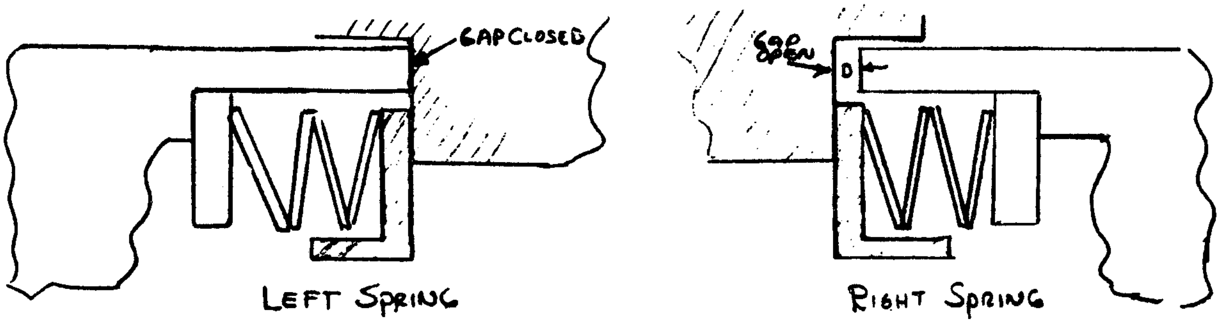
APPENDIX H

NATURAL FREQUENCY OF TURBINE SHAFT IN THE AXIAL DIRECTION

(O. H. Cano)

STRUCTURAL ANALYSIS OF TAA (CONTD)

INSTALLATION OF SPRINGS (DETAIL - SCHEMATIC)



LEFT SPRING - INSTALLED LENGTH SUCH THAT GAP IS CLOSED. PRELOAD REQUIRED 50#

RIGHT SPRING - INSTALLED LENGTH SUCH THAT GAP IS D" AND PRELOAD IN COMPRESSION IS 60#

ABOVE INSTALLATION MEETS REQUIREMENT A Pg 1

1) LEFT BEARING STATIC THRUST LOAD = 50#
2) RIGHT BEARING STATIC THRUST LOAD = 60#

NET LOADING ON LEFT STOP = 10#

CHECK SPRING RATES (APPROXIMATE) AVAILABLE FROM CURVE Ref pg ____

$$\left.\begin{aligned} @\ \delta &= .100 \quad P = 54 \text{ lbs} \\ \delta &= .080 \quad P = 52 \text{ lbs} \end{aligned}\right\}$$ 4 springs in series (Belleville Type

$\Delta P = 2$ lbs
$\Delta\delta = .020$ in

$\therefore k = \frac{2}{.02} = 100$ lb/in

STRUCTURAL ANALYSIS OF TAA (CONTD)

FOR PRELIMINARY ESTIMATE ~ ASSUME k_1 IS THE LEFT SPRING, THEN

$$K_{2\,rigid} \approx \frac{10}{.020} = 500 \ \#/in$$

CHECK VIBRATION CONDITION

$$g = .25 \ @ \ 5-2000 \text{ cps}$$

WEIGHT OF SPRUNG MASS $\approx$ 15 lbs.

$$(.25)(15) = \pm 3.75^{\#}$$

THIS INDICATES THAT DURING NORMAL VIBRATION WITHOUT RESONANCE, THE SPRUNG MASS WILL REMAIN SEATED ON THE LEFT STOP ∴ NO CHATTER (ACTUAL LOAD AT STOP WILL VARY between $13.75^{\#} - 10^{\#} - 6.25^{\#}$)

CHECK FOR RESONANCE POSSIBILITY (CHATTER)

SYSTEM ACTS AS A MASS WITH VERY RIGID SPRING CHARACTERISTICS AS FOLLOWS

$$\delta_{STATIC} = \frac{P_{STATIC}\, L}{AE} = \frac{1^{\#} L}{AE}$$

STRUCTURAL ANALYSIS OF TAA (CONTD)

FOR LOWEST NATURAL FREQUENCY - THE Deflection OF THE LEAST RIGID IS Assumed

FOR A PRELIMINARY ESTIMATE

$$L = 15''$$
$$A = \pi(.1)(3) = 1\,in^2$$

$$\delta_{STATIC} = \frac{15}{1(30)(10^6)}$$

$$k = \frac{(30)(10^6)}{15} = 2(10^6)\ \#/in$$

NATURAL FREQUENCY

$$f_n = \frac{1}{2\pi}\sqrt{\frac{2(10)^6(386)}{15}}$$

$$= 1150\ cps.$$

THE $f_n = 1150$ cps CALCULATION INDICATES THAT the first mode NATURAL frequency IS ABOVE NORMAL OPERATION level of the turbine but below 2000 cps - This INDICATES RESONANT CONDITION SOMEWHERE IN THE RANGE OF 1100 cps. This is NOT considered critical AT this point because of non-linearity of SYSTEM.

$$Amplitude = \frac{(25)(15)}{2(10)^6} = 1.88 \times 10^{-6}$$

APPENDIX I

BEARING NOISE FREQUENCIES

(Z. Vigh)

01-071-002

QUADRILLE WORK SHEET

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

PAGE ______ OF ______ PAGES

DATE ______

SUBJECT ______ BY ______ WORK ORDER ______

ANALYSIS OF BEARING NOISE FREQUENCIES – SIZE 208 TAA BEARING

Sept. 1963

Prepared by:
Z. VIGH

SUBJECT BEARING NOISE BY [signature]

ANALYSIS OF ROLLING ELEMENT BEARING NOISE FREQUENCIES. Given data is:

208 ANG. CONT. BRG.

I.D. = 1.5748 (40 mm)

O.D. = 3.1496 (80 mm)

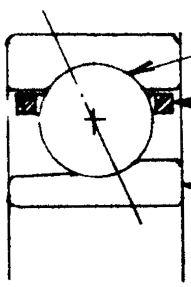
n = 13 No. OF BALLS

d = 15/32 (0.46875)

β = 16° CONT. ANG

N = 12,000 RPM INNER RACE ROTATES

E = 2.3622 (60 mm) PITCH DIA.



f_s = SPIN FREQUENCY OF BALL ABOUT ITS AXIS

f_t' $\begin{cases} f_t = \text{FUNDAMENTAL TRAIN FREQUENCY DUE TO AN IRREGULARITY OF ROLLING ELEMENT OR CAGE} \\ f_r = \text{ROTATIONAL FREQUENCY OF THE SHAFT DUE TO AN UNBALANCE OR ECCENTRICITY} \end{cases}$

(1) $f_r = \frac{N}{60} = \frac{12000}{60} = \underline{200 \text{ CPS}}$ SHAFT ROTATING FREQUENCY

(2) $$f_s = \frac{E f_r}{2d}\left[1 - \left(\frac{d}{E}\right)^2 \cos^2\beta\right]$$

$$= \frac{2.3622 \times 200}{2 \times 0.46875}\left[1 - \left(\frac{0.46875}{2.3622}\right)^2 \cos^2 16°\right]$$

$= 504\left[1 - (0.0392 \times 0.926)\right] = \underline{485 \text{ CPS}}$ BALL SPIN FREQ.

REF. (a) MACHINE DESIGN, MAY 9, '63, Pg. 232
A.J. RUFFINI, "BEARING NOISE"

(3) THE FUNDAMENTAL TRAIN FREQUENCY GENERATED BY THE CAGE ASSEMBLY ROTATING IN THE BEARING IS

$$f_t = \frac{f_r}{2}\left[1 - \frac{d}{E}\cos\beta\right]$$

$$= \frac{200}{2}\left[1 - \frac{0.46875}{2.3622}\cdot 0.96126\right] = \underline{80.9 \text{ CPS}}$$

(4) THE FREQUENCY DUE TO THE RELATIVE SPEED BETWEEN THE TRAIN AND ROTATING INNER RING IS

$$f_t' = \frac{f_r}{2}\left[1 + \frac{d}{E}\cos\beta\right]$$

$$= \frac{200}{2}\left[1 + \frac{0.46875}{2.3622}\, 0.96126\right] = \underline{119.1 \text{ CPS}}$$

(5) THE FREQUENCY DUE TO AN IRREGULARITY ON THE INNER ROTATING RACEWAY BEING CONTACTED BY THE BALLS IS f_{ir}

$$f_{ir} = n f_t' = 13 \times 119.1 = \underline{1550 \text{ CPS}}$$

(6) FREQUENCY DUE TO AN IRREGULARITY ON THE OUTER STATIONARY RACEWAY BEING CONTACTED BY THE BALLS IS f_{is}

$$f_{is} = n f_t = 13 \times 80.9 = \underline{1051 \text{ CPS}}$$

V. TEST RESULTS

To date, the TAA has been subjected to several tests consisting of (1) a gaseous nitrogen test to check the mechanical integrity, L/C system performance and preliminary aerodynamic performance, (2) additional gaseous nitrogen tests as a part of the Cold Gas Electrical System Tests, and (3) preliminary tests in the Rated Power Loop with hot mercury vapor. This section contains test results as follows:

(A) GN_2S-1 - Test Report No. 395/64-00014
- Test Report No. 395/64-00014, Supplement No. 1

(B) CGEST - This test is being reported on by the Electrical Controls Group

(C) RPL-2 - Operation of TAA 3/2 in RPL-2 - TM 4832:65-1-288

Test Report No. 395/64-00014

11 June 1964

TURBINE ALTERNATOR ASSEMBLY TESTING IN GN_2S-1

(FIRST TEST)

TEST NO. D-5-R-3

Written by: C. S. Mah

C. S. Mah
Rotating Machinery Dept.

Approved by: Eber

E. Eber, Dept. Head
Rotating Machinery Dept.
SNAP-8 Division

Von Karman Center
AEROJET-GENERAL CORPORATION

ABSTRACT

TAA No. 1, Buildup No. 1 was tested in GN_2S-1. The basic objectives of the test were to evaluate the lubricant/coolant (L/C) system, the mechanical integrity of the TAA, and the general startup and steady-state characteristics of the TAA with nitrogen as the turbine working fluid. The conditions under which it was tested were as follows:

Nitrogen:

Turbine inlet pressure	77 psia
Turbine inlet temperature	333°F
Turbine exhaust pressure	Ambient

ET-378:

TAA L/C inlet pressure	39.6 and 69.9 psia
TAA L/C inlet temperature	230°F
TAA L/C exit pressure	3.1 and 5.4 psia

The following test results were obtained:

Bearing and slinger losses	.4 ± .1 to .7 ± .1 kw/brg.
Turbine space seal coolant:	
Passage pressure drop	34 psia
Alternator efficiency at 13.5 kw (unity P.F.) output (including bearing and slingers)	86.6 ± 7%
Turbine efficiency	44 ± 3%
Turbine flow	.515 ± .15 lb/sec

The test was considered successful. The only components which did not perform as expected were the turbine space seal heat exchanger and the turbine rotor axial position indicator. The turbine space seal heat exchanger showed a coolant passage drop of 34 psi instead of the anticipated 20 psi at design conditions. The turbine rotor axial position indication did not register axial movement when the thrust-control valve was throttled.

TABLE OF CONTESTS

I. INTRODUCTION

The SNAP-8 Turbine-Alternator Assembly (TAA) was tested on 23 May 1964 in the Gaseous Nitrogen System Loop No. 1 (GN_2S-1) in Building 180. The static test was started at 1430 hours; the dynamic test was started at 1800 hours and was continued for 1 hour, 10 minutes. The test, the first for the TAA, was performed in accordance with References 1 and 2. The TAA that was tested was designated as TAA No. 1, Buildup No. 1 (Drawing No. 093000). The TAA was instrumented as shown in Figure 1.

The basic objectives of the test, as stated in Reference 2, were to evaluate the lubricant/coolant (L/C) system (see Figure 2), the mechanical integrity of the TAA, and the general startup and steady-state characteristics of the TAA with nitrogen as the turbine working fluid.

II. TEST FACILITIES AND INSTALLATION

The test facilities, GN_2S-1, consisted of a nitrogen system, a lubricant/coolant (ET-378) system, controls, and instrumentation as specified in Reference 2. Details of the test facilities are shown in Drawing Nos. 101222, 101278 and E100798. All the data except that which were required for monitoring the safe operation of the TAA were taken on a print-out system called the Digital Data Acquisition System (DDAS). The pertinent data for the monitoring of the operation of the TAA were recorded on strip charts or visually displayed on gages. The data from the visual gages were noted by a test engineer or a technician.

III. TEST PROCEDURE

A. PLANNED PROCEDURE

The detailed test procedure, as planned for the test, is specified in References 3 and 4. Briefly, it is as follows:

1. The L/C system is prepared for operation. The oil is heated to 210°F at the TAA L/C system inlet.

2. Coolant is admitted to the space seal heat exchanger and the alternator coolant passages until the temperature has stabilized.

3. The nitrogen system is prepared to yield the following conditions at the turbine inlet:

Pressure	75 psia
Temperature	315°F

4. Nitrogen is admitted into the turbine.

5. Lubricant is admitted to the bearings.

6. The thrust balancer is adjusted for zero axial thrust in the turbine.

7. Run the TAA at 12,000 rpm until nitrogen is depleted or the test objectives are accomplished.

8. Shut down the test system.

B. TESTING

Static testing was begun at 1530 hours. However, the dynamic testing did not begin until 1800 hours. The dynamic test was continued for 1 hour and 10 minutes. The test was terminated after completion of all testing within the capability of the system.

Several deviations from the planned test procedure had to be initiated because of difficulties encountered during testing. These were as follows:

1. The first deviation was made when it was discovered that the oil (ET-378) temperature at the TAA L/C inlet cannot be reduced to less than 230°F, which was 20° higher than design. However, the bearing outer race temperatures and the alternator stator temperatures were within acceptable limits, so the test was allowed to continue.

2. When the turbine was running at speed (12,000 rpm), the valve on the thrust-balancer line was manipulated to vary the axial thrust on the turbine. However, the axial position indicator did not indicate any turbine shaft movement when the valve was varied from slightly open to fully open. Since there was no axial thrust indication, and the turbine bearings were running cool, the test was continued with the thrust-balancer valve fully open.

3. During the steady-state run at 12,000 rpm, the accelerometers, which were set to alarm at 5 g's, were alarming intermittently. However, when one placed a hand on the test stand, relatively little or no vibration was indicated. It was decided on this subjective basis that the run be permitted to continue to culmination and to have a post-test check made on the accelerometer data.

4. The pressure transducer on the turbine exhaust indicated a pressure less than atmospheric. Inasmuch as the turbine exhausted directly to atmosphere, a turbine exhaust pressure less than atmospheric was very improbable. The test was, therefore, performed with the assumption that the pressure transducer was in error and the turbine exhaust pressure was atmospheric.

C. POST-TEST CHECKS

Post-test checks were made on the components and instruments which did not perform according to expectations. The checks included the following:

1. The space seal heat exchanger for TAA No. 2 was flow checked with MIL-H-5606 oil (properly conditioned ET-378 was not available). The purpose of this check was to compare the pressure drop of the space seal heat exchanger for TAA's 1 and 2 to see whether the pressure drop encountered in TAA No. 1 was to be expected.

2. The space seal heat exchanger (TAA No. 1) was backflushed by re-plumbing the GN_2S-1 L/C system lines. The purpose of backflushing was to determine whether the space seal heat exchanger was clogged with foreign matter.

3. Flow meters F8, F2, F9 and F11 and pressure transducer P-8 were recalibrated because of inconsistent readings.

4. The turbine rotor axial position indicator was checked by manually moving the fourth stage wheel of the turbine from the turbine exhaust opening.

5. The natural frequency of the test stand was checked by lightly hitting the stand and checking the resultant vibrations. The natural frequency of the stand is needed for the analysis of the TAA accelerometer data.

6. The cooler for the ET-378 was checked to determine the cause for lack of cooling of the ET-378.

IV. TEST RESULTS

The post-test checks showed that the pressure drop for the space seal heat exchanger for TAA No. 2 (MIL-H-5606 oil data extrapolated for ET-378 flow of 1600 lb/hr at a temperature of 210°F) is 17 psi as opposed to the ΔP of 33 psia measured for TAA No. 1. The backflushing of the space seal heat exchanger for TAA No. 1 indicated a ΔP of 24 psi at flow of 1400 lb/hr of ET-378 @ 210°F. Extrapolated to a flow of 1600 lb/hr at 210°F the ΔP is 32 psi, approximately the same as the 37 psi for the normal flow.

The recalibration of the flow meters (F8, F2, F9, F11) showed that they were indicating proper flows. However, the recalibration of the pressure transducer for P8 showed it to be in error.

The test data for the first run of TAA No. 1, Buildup No. 1 in GN_2S-1 is included as Appendix A. The data are shown in the reduced form and include data from the DDAS, strip charts and visual gages.

IV. TEST RESULTS (cont'd.)

Figures 3 to 6 show the data in the final form. Figure 3 is a summary of the TAA L/C system data; Figure 4 is a summary of the alternator coolant system data; Figure 5 is a summary of the space seal heat exchanger coolant data; and Figure 6 is a summary of the turbine nitrogen data.

Figure 3 shows that, for an inlet pressure of 39.7 psia and an inlet temperature of 233°F to the TAA L/C system the following bearing inlet flows and bearing outer-race temperatures, bearing outlet flows, and bearing outlet temperatures resulted:

	Inlet Flow lb/hr	Outer Race Temperature °F	Outlet Flow** lb/hr Trans-flow	Reflux Flow	Outlet** Temperature Trans-flow	Reflux Flow
Turbine anti-drive	215	263	157	58	254	270
Turbine drive	200	258	146	54	240	266
Alternator drive	153	270*	90	63	251	270
Alternator anti-drive	192	270*	-	-	252	272

*Thermocouple installed in housing separated from bearing outer race by the bearing clearance, 0.060 in. housing material, and thin layer of electrical insulation.

**Each bearing has two lubricant outlet ports (Figure 3). One directs the lubricant flow that goes through the bearing, the other directs the lubricant that is reflected from the bearing.

Using the above temperatures and flows, the calculated bearing and slinger losses (see Appendix B) are as follows:

Bearing	Bearing and Slinger Losses - kw
Turbine anti-drive	.70
Turbine drive	.39
Alternator drive	.49
Alternator anti-drive	.65

Figure 4 shows a coolant (ET-378) temperature rise of 4°F in the alternator with a coolant flow of 1335 lb/hr at an inlet temperature of 230°F. The alternator output was 13.5 kw (unity power factor).

Using the above values of coolant flow, Δ T, and alternator output, an alternator electrical efficiency of 93% is indicated. Adding the values of bearing and seal losses from the test data yields an alternator efficiency of 86.6% (see Appendix B).

Figure 5 shows that the pressure drop across the space seal heat exchanger is 24 psi with an ET-378 of 1335 lb/hr at 230°F. Extrapolated to 1600 lb/hr and an inlet temperature of 210°F (see Appendix B), the Δ P across the heat exchanger would be 37.4 psi.

Figure 6 shows the following test conditions for the nitrogen in the turbine:

N_2 pressure, turbine inlet	77 psia
N_2 temperature, turbine inlet	333°F
N_2 flow, turbine inlet	.516 lb/sec
N_2 temperature, turbine exhaust	202°F

These values yield a turbine aerodynamic efficiency of 44%. Together with the bearing and slinger loss data, the turbine output power is 22.3 hp or 15.6 kw.

V. DISCUSSION OF RESULTS

A. TESTING

The first test on TAA No. 1, Buildup No. 1 in GN_2S-1 was successful. On the basis of comparison with design data, only the space seal heat exchanger pressure drop is different from the expected values.

The test was run with ET-378, at the entrance of the TAA L/C system, at a temperature of 230°F, or 20°F higher than the design value of 210°F. The higher L/C inlet temperature would result in higher bearing temperatures, higher alternator temperatures, and flow characteristics different from design. However, the resulting operating temperature of the bearings (260-270°F), and the alternator (325°F) were acceptable for short-duration operation, and the system flow characteristics can be reliably extrapolated on the basis of viscosity-temperature relationships. The high L/C system inlet temperature was caused by inadequate cooling in the oil cooler. The post-test check on the oil cooler, (which was a tube-in-shell, double-pass type), indicated that changing the oil flow from the tubes to the shell would enable the ET-378 to be cooled to design temperature (210°F).

B. SPACE SEAL HEAT EXCHANGER PRESSURE DROP

The space seal heat exchanger had a pressure drop higher than expected. The consequence of this high pressure drop was a lower flow through the TAA coolant loop. For TAA operation in a Hg loop, this lower flow can mean that the space does not get adequate cooling, resulting in excessive space seal leakage. The lower flow can also mean that the coolant leaves the space seal and enters the alternator at a higher temperature. The alternator will then operate at higher than design temperature because of higher coolant temperature and lower heat transfer.

The heat exchanger for TAA No. 2 was flow-checked (with MIL-H-5606 oil) to determine whether the problem exists in the second unit. The results showed that the TAA No. 2 space seal heat exchanger will have a pressure drop of 17 psi for ET-378 service at design conditions, a value consistent with the design value of 20 psi. This flow check indicates that the problem of high pressure drop in the TAA No. 1 space seal heat exchanger may be unique.

The backflushing of the TAA No. 1 space seal heat exchanger yielded indifferent results. No particles were found and ΔP did not change significantly. The heat exchanger passages may still be clogged with contaminants despite the flushing operation. On the other hand, the high pressure loss might be inherent in the heat exchanger due to some fabrication problem.

Regardless of the cause, a high pressure drop exists across the TAA No. 1 space seal heat exchanger. Partial solutions to this problem, short of disassembling the TAA and replacing the heat exchanger, are to take out the flow-balancing orifice in the TAA coolant loop or provide a controlled parallel loop to the space seal or both. Removing the orifice will increase the flow in the TAA coolant loop to near design. The parallel loop to the space seal heat exchanger, if needed, will insure that the alternator will get the design cooling flow. Excessive leakage from the space seal may occur because of inadequate cooling. However, the consideration of the expected life of the rubbing face seals and the proposed length of operation for TAA No. 1 before reassembly indicates that this will not be a major problem.

C. THRUST BALANCER

The axial position indicator indicated no turbine shaft axial movement when the valve opening on the turbine thrust balancer line was varied. This result, while significant, does not apply to the future Hg tests because of different pressures and different sonic velocities of the N_2 and Hg.

D. <u>ALTERNATOR</u>

The alternator has been tested at power outputs from 20 kw to 60 kw (unity power factor). Extrapolating these data to the 13.5 kw output of the first test in GN_2S-1 of TAA No. 1, Buildup No. 1, the indicated efficiency is 74% (Figure 7). This efficiency includes bearing and slinger losses of 2.9 kw.

The GN_2S-1 test results (see Appendix D) show an alternator efficiency of 93% based on the alternator coolant flow and temperature rise. Adding to this electrical efficiency the bearing and slinger losses, the alternator efficiency is 86.7%.

Another method of calculating alternator efficiency is to base it on the turbine power output. This also yields an alternator efficiency of 86.6%.

The 86+% alternator efficiency is based on a bearing and slinger loss of 1.16 kw. If this is increased to 2.9 kw to be consistent with the alternator test data, the alternator efficiency is 78.1%, or within 4% of the alternator data.

Several factors in the performance of the alternator bearings and slingers are worthy of comment. These include the lubricant flow to the bearings, the distribution of lubricant for bearing cooling (lubrication) and slinger cooling (alternator rotor cooling), the bearing outer-race temperatures, and the bearing and slinger power losses.

The test data showed a flow of less than the design flow of 200 lb/hr to the bearings. This is the result of the disparity between the test pressure at the bearing inlet of 23 psia as compared to a design pressure of 33 psia. The disparity between the test and the design pressure is the result of the changing of the design concept from orificing each bearing lubricant inlet line to orificing the lubricant inlet manifold. It should be noted that the measured flows are consistent with data obtained from the alternator tests.

The flow distribution to the two bearing slingers is as expected. A third of the total bearing lubricant flow is injected across the bearing, while two-thirds of the flow is used to cool the alternator rotor by way of the inboard slinger. Note that the alternator rotor electrical losses are nearly independent of the alternator power output, and the cooling requirements for the reduced-power test are the same as the cooling requirements for a full-power test.

The outer-race temperature* of the alternator bearings was at 270°F during the test. This is about 20°F higher than the design value. However, considering that the lubricant inlet temperature is also 20°F too high, the resulting outer-race temperature for the test is to be expected.

*See page 4.

D. ALTERNATOR (cont'd.)

The bearing and slinger losses are shown to be about the same as the 0.86 kw/bearing anticipated (Figure 2). The fact that the test was run with ET-378 at a higher temperature (therefore lower viscosity) might have a small influence on the results.

E. TURBINE

The turbine had an efficiency of 44% on the test. This is within instrumentation accuracy of the anticipated efficiency of 47.5% (see Appendix E).

The theoretical turbine efficiency is an aerodynamic efficiency; it includes the interstage labyrinth leakage and the thrust balancer leakage but not the bearing and slinger losses. The theoretical turbine thermo-aerodynamic characteristics are as follows:

	Overall	1st Stage	2nd Stage	3rd Stage	4th Stage
Inlet pressure	75	75	52	27	18
Outlet pressure	15	51	26.7	17.7	15
Pressure ratio	0.2	0.72	0.51	0.66	0.83
U/C_o	0.14	0.26	0.21	0.26	0.45
η	0.51	0.46	0.38	0.55	0.70
η Incl. Leakage	0.475				
$\dot{w}$ Incl. Leakage	0.51				

Under the N_2 test conditions, the second stage of the turbine is the only choked stage (pressure ratio $<$ 0.528) and it is the stage in which the most energy from the gas is taken out. The last stage, with a small pressure drop from 18 to 15 psia, does practically no work.

The theoretical turbine efficiency is based on the estimate that the turbine will be at least 60% efficient in the Hg system. TAA No. 1 has an oversized thrust-balancing piston and twice the design interstage labyrinth clearances, and therefore increased leakage losses. Since the test results are still comparable to the theoretical results, it may be concluded that the final turbine design has a high probability of achieving at least 60% efficiency in Hg service.

The turbine bearings and slingers performed as expected in every way. The bearing flow, the lubricant distribution through each bearing, the bearing race temperature, and the bearing and slinger losses all agree with the theoretical values within the accuracy of the instrumentation.

VI. CONCLUSIONS

A. The test was completely successful. All TAA components performed as expected with the exception of the high pressure drop across the space seal heat exchanger.

B. Changes are required on the alternator lube injectors and the orifice in the TAA coolant loop to better balance the L/C flow.

C. The bearing and slinger losses average about 0.6 ± .1 kw/bearing.

D. The bearing outer-race temperatures are 260-270°F, with the lubricant at a temperature 20°F higher than design at the inlet of the TAA L/C system.

E. The alternator efficiency is 86.5 ± 7% including bearing losses.

F. The turbine aerodynamic efficiency is 44 ± 3%; the efficiency including bearing and seal losses is 39 ± 4%.

G. More testing is required to complete the objectives specified in Reference 2.

REFERENCES

1. Test Plan for Turbine Alternator Assembly Testing in GN_2S-1, TP No. 395/64-0004 (Revised), 29 April 1965

2. AGC SNAP-8 Division Test Request for TAA No. 1, Buildup No. 1 (P/N 093000) GN_2S-1 Checkout Tests, TR No. 395/64-0010 (D5R) Revised, 19 May 1964

3. Test Operating Procedure for GN_2S-1, TAA No. 1, Buildup No. 1 - Static Tests, GN_2S-1-034, Document No. 371.0258-JAB, 20 May 1964

4. TAA Operating Procedure for GN_2S-1 Rotational Tests to TAA No. 1, Buildup No. 1, GN_2S-1-032

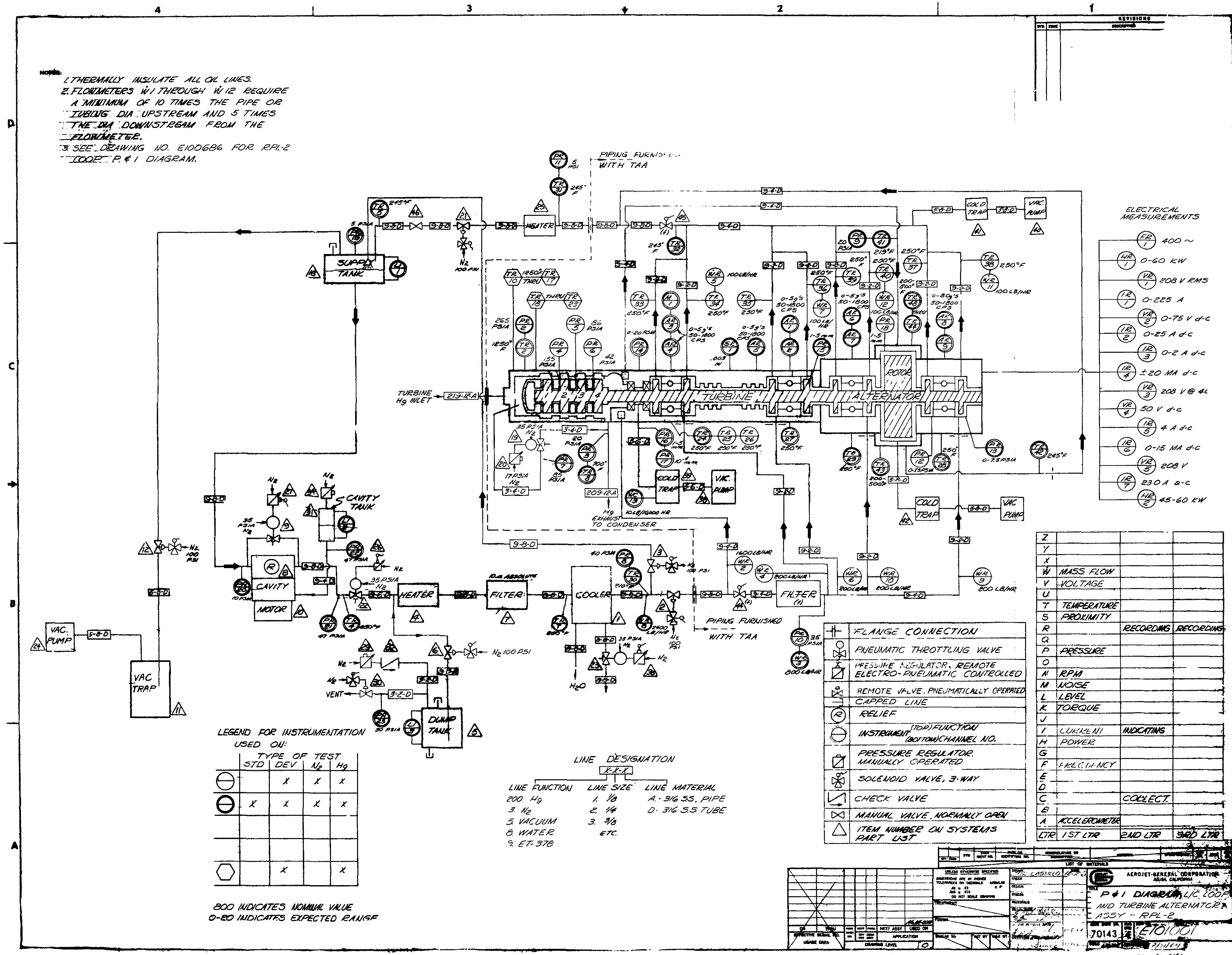
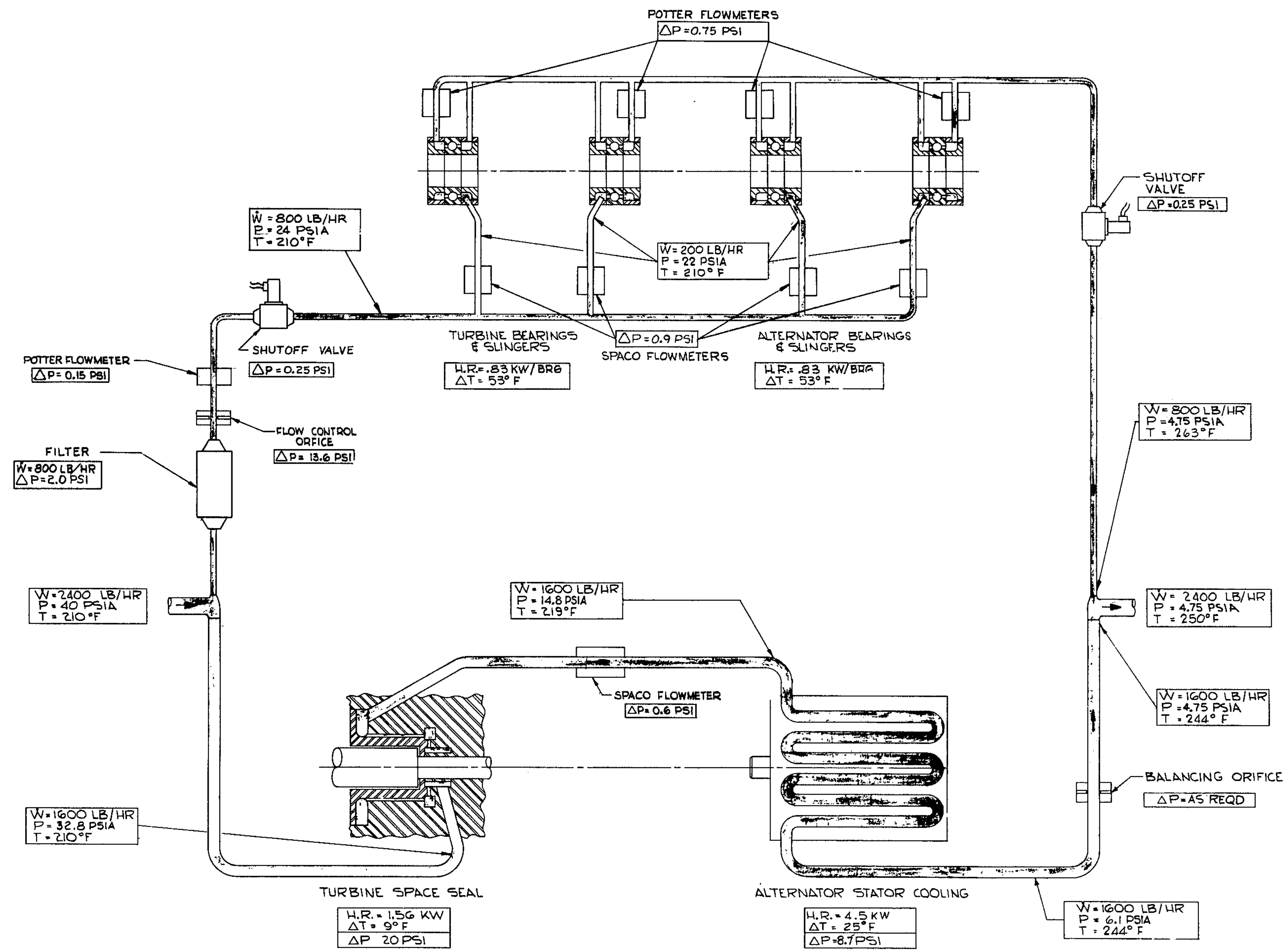

NOTES:
1. THERMALLY INSULATE ALL OIL LINES.
2. FLOWMETERS W/1 THROUGH W/12 REQUIRE A MINIMUM OF 10 TIMES THE PIPE OR TUBING DIA. UPSTREAM AND 5 TIMES THE DIA DOWNSTREAM FROM THE FLOWMETER.
3. SEE DRAWING NO. E100686 FOR RPL-2 LOOP P.&I DIAGRAM.
PIPING FURNISHED WITH TAA
TURBINE Hg INLET
TURBINE
ALTERNATOR
ROTOR
SUPPLY TANK
HEATER
FILTER
COOLER
CAVITY TANK
CAVITY
MOTOR
DUMP TANK
COLD TRAP
VAC. PUMP
VAC TRAP
Hg EXHAUST TO CONDENSER
ELECTRICAL MEASUREMENTS
400 ~
0-60 KW
208 V RMS
0-225 A
0-75 V d-c
0-25 A d-c
0-2 A d-c
±20 MA d-c
208 V @ 4L
50 V d-c
4 A d-c
0-15 MA d-c
208 V
230 A a-c
45-60 KW
LEGEND FOR INSTRUMENTATION USED ON:
TYPE OF TEST
STD DEV N2 Hg
800 INDICATES NOMINAL VALUE
0-20 INDICATES EXPECTED RANGE
LINE DESIGNATION
X-X-X
LINE FUNCTION
200 Hg
3. N2
5. VACUUM
8. WATER
9. ET-378
LINE SIZE
1. 1/8
2. 1/4
3. 3/8
ETC.
LINE MATERIAL
A. 316 S.S. PIPE
D. 316 S.S. TUBE
FLANGE CONNECTION
PNEUMATIC THROTTLING VALVE
PRESSURE REGULATOR, REMOTE ELECTRO-PNEUMATIC CONTROLLED
REMOTE VALVE, PNEUMATICALLY OPERATED
CAPPED LINE
RELIEF
INSTRUMENT (TOP) FUNCTION (BOTTOM) CHANNEL NO.
PRESSURE REGULATOR MANUALLY OPERATED
SOLENOID VALVE, 3-WAY
CHECK VALVE
MANUAL VALVE, NORMALLY OPEN
ITEM NUMBER ON SYSTEMS PART LIST
A ACCELEROMETER
C COLLECT
F FREQUENCY
H POWER
I CURRENT INDICATING
K TORQUE
L LEVEL
M NOISE
N RPM
P PRESSURE
R RECORDING RECORDING
S PROXIMITY
T TEMPERATURE
V VOLTAGE
W MASS FLOW
LTR 1ST LTR 2ND LTR 3RD LTR
AEROJET-GENERAL CORPORATION AZUSA, CALIFORNIA
P&I DIAGRAM LIQ. LOOP AND TURBINE ALTERNATOR ASSY - RPL-2
70143 E101001

Figure 1

NOTES:

1. LUBE & COOLANT FLUID - DOW CHEMICAL CO. ET-378

SYM	ZONE	REVISIONS DESCRIPTION	DATE	APPROVED
A		REDRAWN WITH CHANGES SEE N/C DRAWING FOR WAS CONDITION	4/10/64	



FOR RECORD ONLY
DO NOT FABRICATE
TO THIS PRINT

PRELIMINARY

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

FLOW DIAGRAM,
LUBE & COOLING SYSTEM -
TURBINE - ALTERNATOR ASSY

DRAWN H. PENNY 1-1-63
CODE IDENT NO. 70143 SIZE E DWG NO. 088485
SCALE NONE RELEASE DATE 5-1-64

0741-11-2000

088485 A

Figure 2

Page V-16

BEARING & SLINGER PERFORMANCE

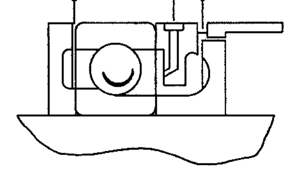
FIRST TEST GN_2 S-1 (D-5-R-3)

TAA No. I

	DESIGN	TEST
TEMP	210°F	230°F
PRESS	24 PSIA	23.3 PSIA
FLOW	200 LB/HR	215 LB/HR

	DESIGN	TEST
TEMP	263°F	254°F
PRESS	5.2 PSIA	4.9 PSIA
FLOW	100 LB/HR	157 LB/HR

	DESIGN	TEST
TEMP	263°F	270°F
PRESS	5.2 PSIA	3.1 PSIA
FLOW	100 LB/HR	58 LB/HR

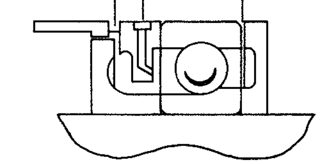


TA ANTIDRIVE

	DESIGN	TEST
TEMP	210°F	230°F
PRESS	24 PSIA	23.3 PSIA
FLOW	200 LB/HR	200 LB/HR

	DESIGN	TEST
TEMP	263°F	266°F
PRESS	5.2 PSIA	3.1 PSIA
FLOW	100 LB/HR	54 LB/HR

	DESIGN	TEST
TEMP	263°F	240°F
PRESS	5.2 PSIA	4.7 PSIA
FLOW	100 LB/HR	146 LB/HR

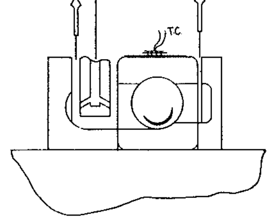


TA DRIVE

	DESIGN	TEST	ALT. TEST
TEMP	210°F	230°F	205°F
PRESS	24 PSIA	23.3 PSIA	24.7 PSIA
FLOW	200 LB/HR	153 LB/HR	195 LB/HR

	DESIGN	TEST	ALT. TEST
TEMP	265°F	270°F	248°F
PRESS	5.2 PSIA	3.1 PSIA	4.7 PSIA
FLOW	100 LB/HR	90 LB/HR	157 LB/HR

	DESIGN	TEST	ALT. TEST
TEMP	263°F	251°F	267°F
PRESS	5.2 PSIA	3.4 PSIA	6.7 PSIA
FLOW	100 LB/HR	63 LB/HR	36.5 LB/HR

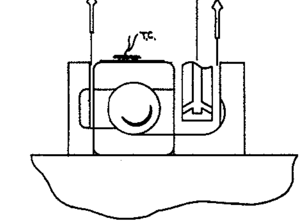


AA DRIVE

	DESIGN	TEST	ALT. TEST
TEMP	210°F	230°F	195°F
PRESS	24 PSIA	23.3 PSIA	20.7 PSIA
FLOW	200 LB/HR	192 LB/HR	168 LB/HR

	DESIGN	TEST	ALT. TEST
TEMP	263°F	272°F	276°F
PRESS	5.2 PSIA	—	6.7 PSIA
FLOW	100 LB/HR	—	35 LB/HR

	DESIGN	TEST	ALT. TEST
TEMP	265°F	252°F	221°F
PRESS	5.2 PSIA	3.1 PSIA	2.7 PSIA
FLOW	100 LB/HR	—	122 LB/HR



AA ANTIDRIVE

PERFORMANCE SUMMARY

	TA ANTIDRIVE		TA DRIVE		AA DRIVE		AA ANTIDRIVE	
	PREDICTED	TEST	PREDICTED	TEST	PREDICTED	TEST*	PREDICTED	TEST*
BEARING AND SLINGER LOSSES	0.83 KW	0.7 KW	0.83 KW	0.39 KW	0.83 KW	0.49 KW	0.83 KW	0.65 KW
OUTER RACE TEMP AT DESIGN FLOW	267°F	263°F	249°F	263°F	—	270°F	—	273°F
OUTER RACE TEMP AT 135% DESIGN INLET FLOW	—	252°F	—	255°F	—	264°F	—	256°F

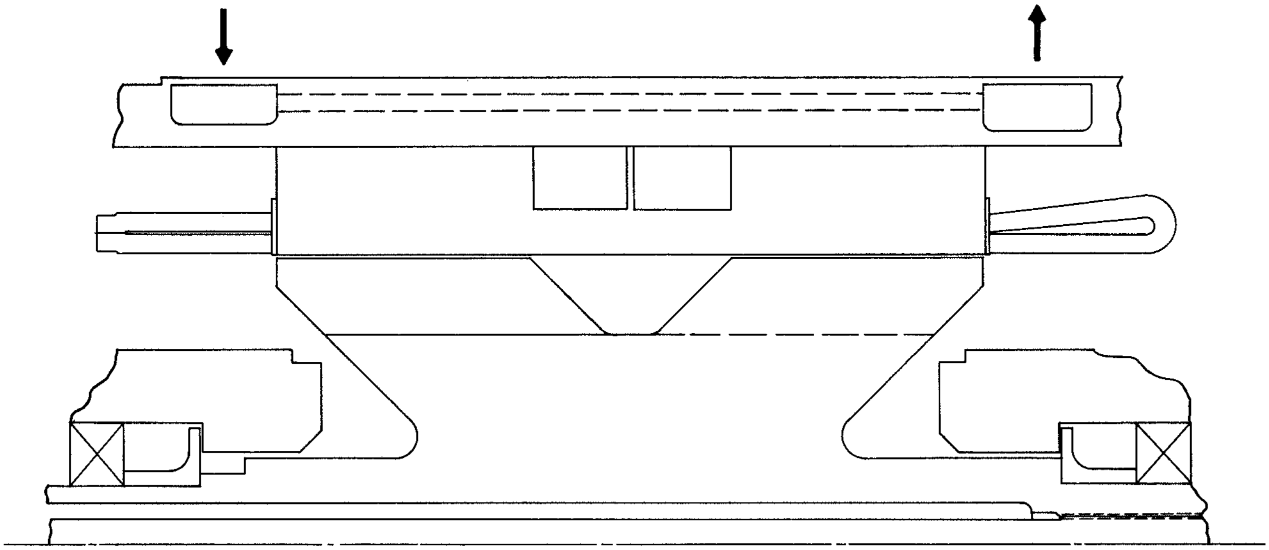
*THERMOCOUPLE INSTALLED AS SHOW ABOVE

Figure 3

ALTERNATOR PERFORMANCE
FIRST GN_2S-I TEST
TAA #1
(TEST D-5-R-3)

	DESIGN AT 45 KW OUTPUT	TEST AT 13.5 KW OUTPUT
TEMP	210° F	230° F
PRESS.	18 PSIA	16 PSIA
FLOW	1600 LBS/HR	1335 LBS/HR

	DESIGN AT 45 KW OUTPUT	TEST AT 13.5 KW OUTPUT
TEMP	215° F	234° F
PRESS.	9.3 PSIA	10 PSIA
FLOW	1600 LBS/HR	1335 LBS/HR



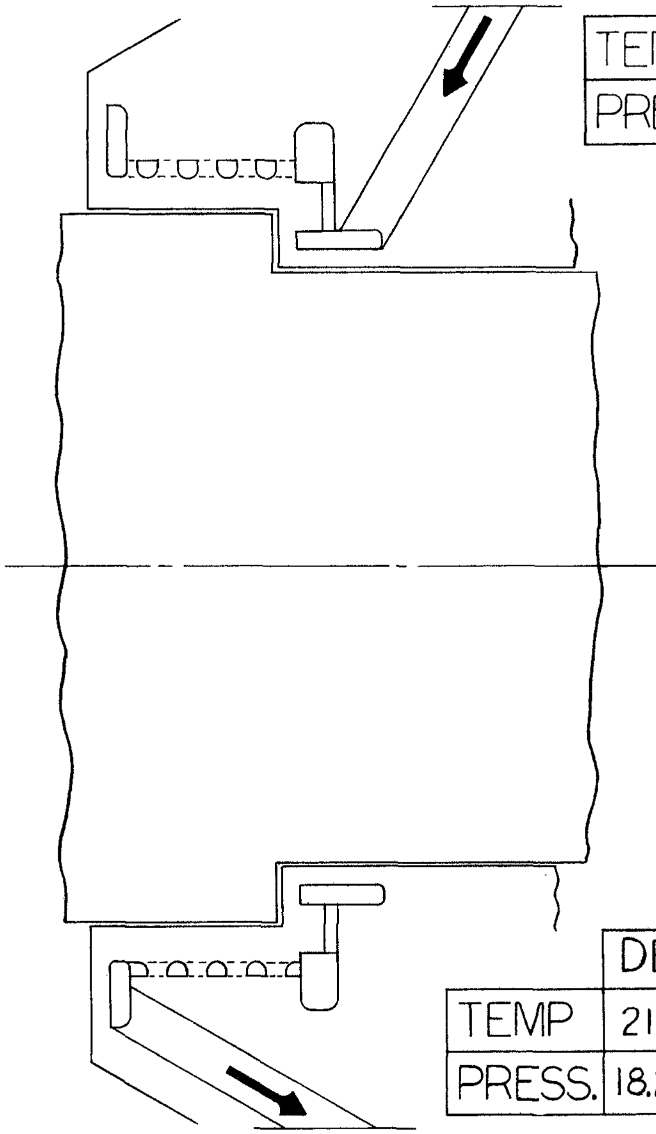
PERFORMANCE SUMMARY		
	PREDICTED	TEST
ALT ELECT. EFFICIENCY	90%	93%
* BEARING & SLINGER LOSSES	0.83 KW/BRG	0.65 KW/BRG
ALTERNATOR EFFICIENCY	81%	86%
COOLANT ΔT	4.1° F	4° F
COOLANT ΔP	8.7 PSI	6 PSI

* FROM FIGURE 2

Figure 4

TURBINE SPACE SEAL HEAT EXCHANGER PERFORMANCE
FIRST GN_2S-1 TEST (D-5-R-3)
TAA #1

	DESIGN	TEST
TEMP	210° F	230° F
PRESS.	40 PSIA	69.9 PSIA



	DESIGN	TEST
TEMP	219° F	(230° F)
PRESS.	18.2 PSIA	27 PSIA

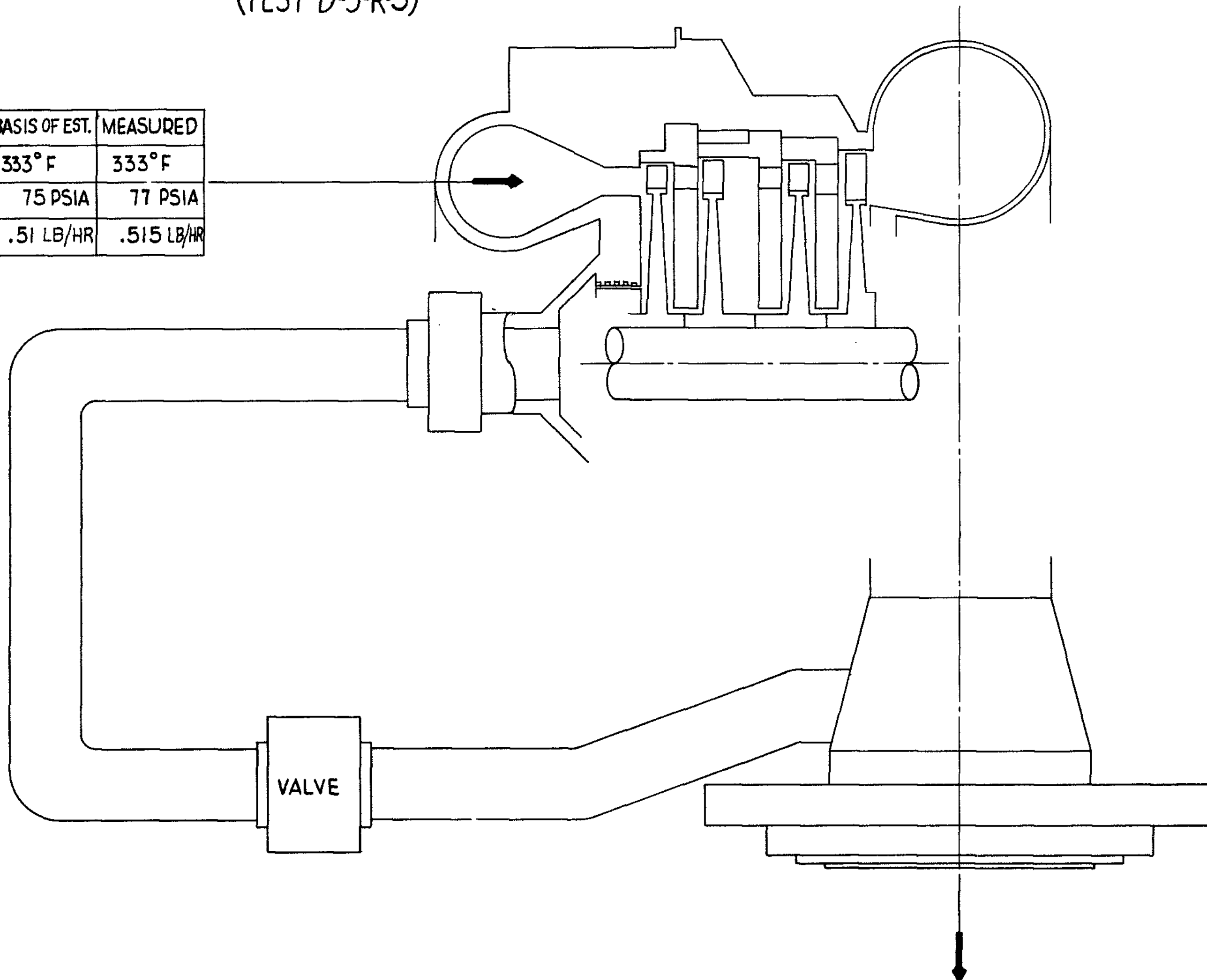
PERFORMANCE SUMMARY		
	PREDICTED	TEST
ΔP ACROSS HEAT EXCHANGER	20 PSI	34 PSI
HEAT TRANSFERRED	1.56 KW	—

Figure 5

TURBINE PERFORMANCE
FIRST TEST - GN_2 S-1
TAA No. 1
(TEST D-5-R-3)

	BASIS OF EST.	MEASURED
TEMP	333°F	333°F
PRESS	75 PSIA	77 PSIA
FLOW	.51 LB/HR	.515 LB/HR

SUMMARY
ESTIMATED PERFORMANCE - 47.5%
MEASURED PERFORMANCE - 44 %



	ESTIMATED	MEASURED
TEMP	194°F	202°F
PRESS	15 PSIA	—

Figure 6

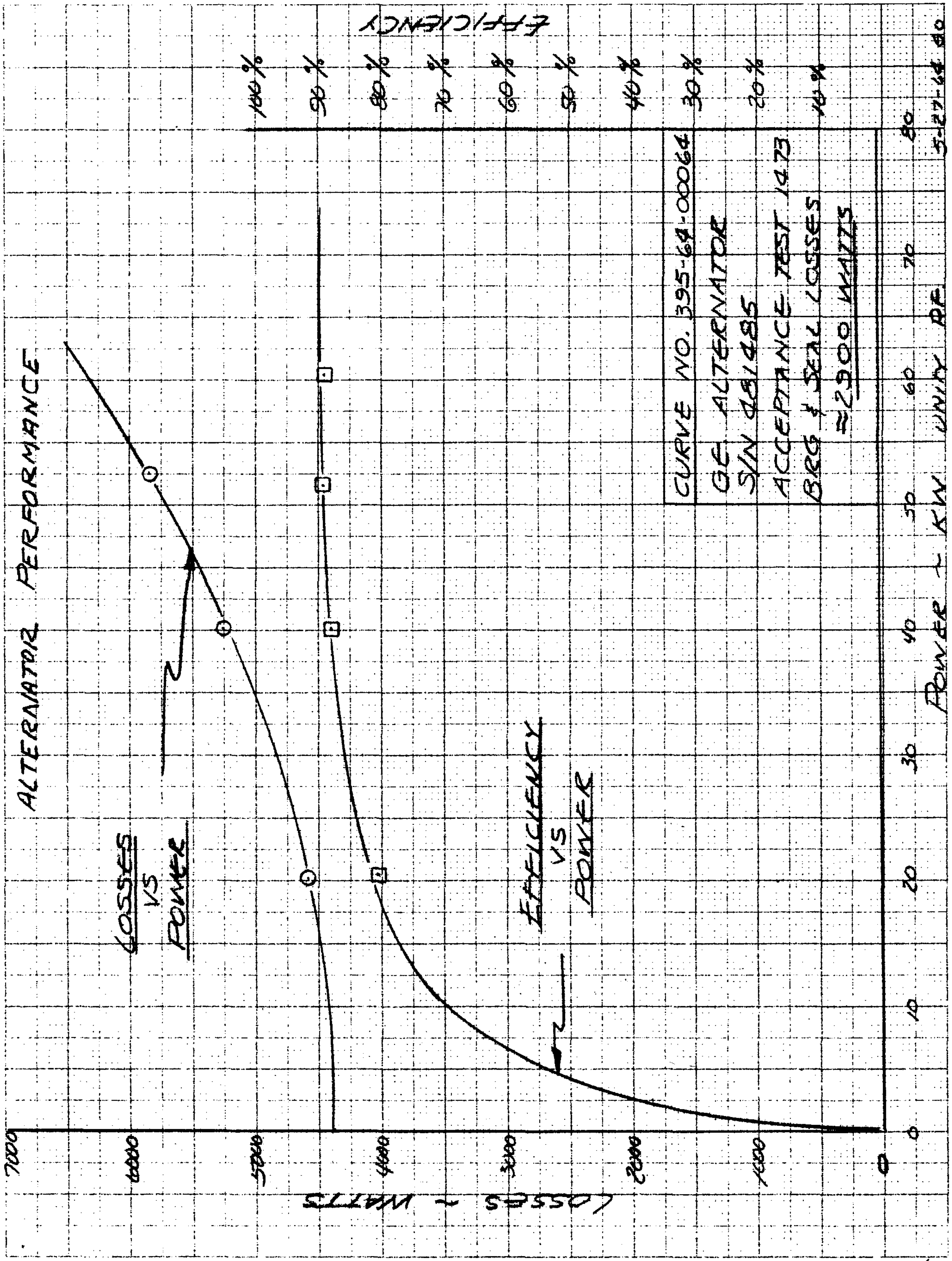

ALTERNATOR PERFORMANCE
LOSSES VS POWER
EFFICIENCY VS POWER
CURVE NO. 395-64-00064
GE ALTERNATOR
S/N 481485
ACCEPTANCE TEST 1473
BRG & SEAL LOSSES
≈2900 WATTS
POWER ~ KW UNITY PF
LOSSES ~ WATTS
EFFICIENCY
0
1000
2000
3000
4000
5000
6000
7000
0
10
20
30
40
50
60
70
80
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
5-27-64

Figure 7

APPENDIX A

DATA SHEETS FROM TEST D-5-R-3

AEROJET GENERAL

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

QUADRILLE WORK SHEET

DATE RUN 5-23-67
SUBJECT GN2S-1, TAA D-5-R-3 BY J.J. Walker
WORK ORDER

DATA POINT EXPLANATION.

(1) REQUESTED: 1 DATA POINT PRIOR TO START UP.

RESPONSE: DATA POINT AT 1806 HRS.

(2) REQUESTED: 1 DATA POINT JUST AFTER START UP.

RESPONSE: DATA POINT AT 1815 HRS.

(3) REQUESTED: 1 DATA POINT AT 6,000 RPM.

RESPONSE: NOT AVAILABLE SINCE SPEED WENT FROM 900 TO 11,340 RPM IN ABOUT 60 SECONDS.

(4) REQUESTED: 1 DATA POINT AFTER OPENING SOLENOID VALVES AND BEFORE COMING UP TO SPEED.

RESPONSE: NOT AVAILABLE AT THESE CONDITIONS SINCE VALUE OPENED AFTER COMING UP TO SPEED. SUBSTITUTED 1 DATA POINT AT 1824 HRS AND 40 SEC. (SPEED AT 9,630 RPM).

(5) REQUESTED: 6 DATA POINTS AT RATED SPEED; 3 NEAR START AND 3 NEAR END OF RUN.

RESPONSE: 6 DATA POINTS AT 1828, 1830, 1832, 1854, 1856, AND 1901 HRS.

QUADRILLE WORK SHEET

AEROJET GENERAL

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

DATE RUN 5-23-64

SUBJECT GN2S-1, TAA D-5-R-3 BY J Walker

WORK ORDER

(6) REQUESTED: 1 DATA POINT IMMEDIATELY AFTER SHUT DOWN.

RESPONSE: DATA POINT AT 1922 HRS.

(7) REQUESTED: 1 DATA POINT AT ABOUT 30 MIN. AFTER SHUT DOWN.

RESPONSE: DDAS FUNCTIONS ONLY AT 1938 HRS. (17 MINUTES AFTER SHUT DOWN. RECORDERS NOT RUNNING AT THIS TIME.)

Purpose DATA POINTS AS REQUESTED BY NASA ON 5-26-64.

PRELIMINARY DATA
SNAP-8 DIVISION

REF: TM372:63-8-149

Calibration Corrected and Approved Format for Internal Distribution Only

SNAP-8
DATA REDUCTION SHEET

Page 1 of 3

Prepared by	[illegible]	[illegible]
Checked by	[illegible]	[illegible]
Approved by	[illegible]	6/18/64

Date 5-23-64
Item [illegible] TAA
Test No. D-5-R-3
W. O. No. 0712-33-22:5

TIME (RECORDER CLOCK)				1806	1815	1824+	1828	1830	1832	1854	1856	1901	1922	1938
FUNCTION						40 SEC								
T-4	DDAS	232	°F	210	213	224	237	244	248	247	246	246	230	177
T-30	REC	24A	°F	211	214	222	231	239	242	232	230	229	224	NA
T-42	DDAS	251	°F	207	212	220	230	237	238	236	230	235	227	204
T-33	REC	8B-2	°F	81	81	232	257	265	270	270	273	270	N.A.	NA
T-34	DDAS	245	°F	88	90	222	245	250	252	256	254	253	187	170
T-32	DDAS	244	°F	115	119	226	247	255	255	260	257	258	225	146
T-35	DDAS	246	°F	96	94	234	255	262	262	265	267	265	229	176
T-36	REC	8B-3	°F	78	78	208	225	234	238	242	238	238	N.A.	NA
T-27	REC	6A	°F	171	171	230	247	255	262	263	264	263	254	NA
T-24	REC	9B-2	°F	180	181	224	244	252	262	263	[illegible]	263	N.A.	NA
T-25	DDAS	H.S.	°F	162	164	201	217	222	220	227	227	226	232	222
T-26	DDAS	H.S.	°F	182	184	224	232	244	239	243	242	242	259	249
T-29	DDAS	H.S.	°F	194	195	244	264	272	271	269	271	270	259	250
T-39	REC.	8A-1	°F	99	95	232	255	263	268	270	275	273	NA	NA
T-40	DDAS	250	°F	82	81	225	242	248	249	252	251	250	175	139
T-43	REC	9B-4	°F	205	206	216	223	226	230	252	252	256	N.A.	NA
T-37	REC	8B-4	°F	74	74	[illegible]	[illegible]	96	257	254	256	255	N.A.	NA
T-28	DDAS	H.S.	°F	186	187	236	256	264	268	271	273	273	256	247
T-38	DDAS	247	°F	78	76	241	267	274	269	269	[illegible]	272	[illegible]	159
T-44	DDAS	256	°F	231	231	255	268	275	281	303	304	304	307	305
T-45	REC	8A-3	°F	230	233	[illegible]	309	[illegible]	326	326	328	[illegible]	N.A.	NA
T-46	DDAS	257	°F	NA	N.A.	N.A.	N.A.	NA	N.A.	NA	NA	NA	NA	NA
T-47	DDAS	260	°F	257	[illegible]	[illegible]	[illegible]	224	517	483	258	[illegible]	327	294
T-48	DDAS	261	°F	NA	NA	N.A.	N.A.	NA	N.A.	NA	NA	NA	NA	NA
T-31	DDAS	237	°F	210	214	227	247	254	244	242	[illegible]	[illegible]	230	196
T-5	DDAS	233	°F	212	214	227	241	247	250	249	248	[illegible]	230	159
PV1 - PR. VENTURI INLET.			PSIA	SET AT .300 PSIA FOR ENTIRE RUN										
ΔP-71	REC	23B	PSID	0.02	0.08	1.76	1.77	1.77	1.80	1.81	1.82	1.82	0	
T-1	REC	25A	°F	81	190	316	323	326	327	334	334	333	263	
F-1	CALCULATED.		LB/SEC.	NA	N.A.	.510	.510	.510	.513	.575	.573	.516	0	

A-3

Purpose SEE P.1

PRELIMINARY DATA

SNAP-8 DIVISION

REF: TM372:63-8-149

Calibration Corrected and Approved Format for Internal Distribution Only

SNAP-8
DATA REDUCTION SHEET

Page 2 of 3

Prepared by	[illegible]	[illegible]
Checked by	[illegible]	6-5-64
Approved by	[illegible]	6/8/64

Date 5-23-64
Item [illegible] 3AA
Test No. D-5-R-3
W. O. No. 0742-63-2205

TIME (RECORDER CLOCK)				1806	1815	1824+	1828	1830	1832	1854	1856	1901	1922	1938
FUNCTION	INSTR.	POSITION	UNITS			40 SEC								
P-2	REC	22B	PSIA	16	21	75	75	75	75	75	76	77	16	NA
T-2	REC	9B-1	°F	94	195	315	320	323	323	329	329	329	N.A.	NA
P-7	DDAS	130	PSIA	14	16.5	45.5	44.9	45.4	45.9	45.5	45.7	45.8	13	12.6
"	REC	14-B-	→	—	—	—	—	—	—	—	—	—	—	—
P-3	DDAS	117	PSIA	N.A.	BAD	X-DUCER								
"	REC.	14B-1	PSIA	"	"	"								
T-8	REC	9B-3	°F	210	320	342	335	335	343	350	355	355	N.A.	NA
T-9	DDAS	535	°F	115	182	198	192	192	195	201	202	201	200	157
D-1	DDAS	H.S.	INCHES	.0027	.0027	.0027	.0026	.0026	.0026	.0025	.0025	.0025	.0024	.0025
Z-1	DDAS		RPM	0	900	9,630	11,940	12,120	11,940	12,120	11,910	12,120	0	0
P-20	DDAS	143	PSIA	3.10	3.10	2.98	2.86	2.84	2.87	2.86	2.87	2.87	2.24	21.23
P-21	REC	24B	PSIA	61	63	73	72	67	67	64	36	36	66	NA
P-8	REC	26A	PSIA	65	68	73	71	70	68	65	40	39	71	[illegible]
P-16		VISUAL	PSIA	NO READINGS TAKEN										
P-12	DDAS	137	PSIA	0.1	0.1	2.48	1.10	.95	0.1	0.1	0.1	0.1	0.1	1.97
P-13	DDAS	140	PSIA	N.A.	N.A	NA	N.A	NA	NA	NA	NA	NA	N.A.	NA
P-11	REC	26B	PSIA	1.25	1.25	5.87	5.75	5.75	5.75	5.75	3.80	3.65	1.55	NA
P-19	REC	25-B	PSIA	0.60	0.60	0.60	0.60	0.61	0.62	0.70	0.72	0.73	0.70	NA
P-16		VISUAL	PSIA	NO READINGS TAKEN.										
P-17			PSIA	NOT TAKEN										
P-10	REC	11A	PSIA	0	0	45	43	42	41	39	36	23	24	[illegible]

A-4

Purpose SEE P. 1

PRELIMINARY DATA

SNAP-8 DIVISION

REF: TM372:63-8-149

Calibration Corrected and Approved
Format for Internal Distribution Only

SNAP-8
DATA REDUCTION SHEET

Page 3 of 3

Prepared by	[illegible]	6-6-64
Checked by	[illegible]	[illegible]
Approved by	[illegible]	6/9/64

Date 5-23-64
Item [illegible] TAA
Test No. D-5-R-3
W. O. No. 0742-63-2205

TIME (RECORDER CLOCK)				1806	1815	1824+	1828	1830	1832	1854	1856	1901	1922	1938
FUNCTION	INSTR.	POSITION	UNITS			40 SEC.								
F-8	REC	23A	GPM	3.15	3.24	5.19	5.15	5.15	5.11	4.98	3.74	3.67	3.41	NA
"			LB/HR	1780	1830	2910	2880	2865	2845	2780	2090	2055	1910	NA
F-2	DDAS	66	GPM	3.22	3.30	3.40	3.36	3.32	3.29	2.94	2.37	2.34	3.33	
"			LB/HR	1820	1855	1910	1885	1850	1830	1640	1325	1305	1865	
F-3	REC	22A	GPM	0	0	1.88	1.81	1.81	1.81	1.72	1.37	1.37	0	NA
"			LB/HR	0	0	1060	1015	1010	1010	990	770	755	0	NA
F-4	REC	9A-4	GPM	0	0	.543	.540	.530	.521	.505	.373	.369	NA	NA
"			LB/HR	0	0	310	305	300	295	290	215	210	NA	NA
F-6	REC	9A-3	GPM	0	0	.490	.480	.485	.474	.466	.360	.355	NA	NA
"			LB/HR	0	0	280	270	275	270	265	210	205	NA	NA
F-10	REC	9A-1	GPM	0	0	.372	.379	.381	.380	.394	.279	.277	NA	NA
"			LB/HR	0	0	215	220	220	215	220	160	160	NA	NA
F-9	REC	9A-2	GPM	0	0	.418	.575	.587	.616	.610	.673	.634	NA	NA
"			LB/HR	0	0	240	325	330	350	350	385	360	NA	NA
F-5	DDAS	67	GPM	0	0	.261	.306	.313	.305	.311	.263	.257	0	0
"			LB/HR	0	0	150	180	185	180	180	160	145	0	0
F-7	DDAS	70	GPM	0	0	.319	.356	.359	.351	.326	.263	[illegible]	0	0
"			LB/HR	0	0	185	205	210	200	185	155	155	0	0
F-11	DDAS	71	GPM	0	0	.365	.372	.374	.178	.159	.215	.213	0	0
"			LB/HR	0	0	210	215	215	105	90	125	125	0	0
F-12	DDAS	72	GPM	0	0	[illegible]	.155	.157	.155	.136	.112	.112	0	0
"			LB/HR	0	0	105	90	90	90	80	70	70	0	0
E-1	REC	8A-4	VOLTS	0	7.8	95.4	97.8	98.5	100.4	101.7	103.8	103.1	NA	NA
E-2	DDAS	55	VOLTS	0	8.1	95.8	98.1	98.9	102.1	102.8	105.0	105.0	0	0
E-3	DDAS	56	VOLTS	0	7.6	90.3	93.0	92.8	96.1	97.4	99.4	99.8	0	0
I-1	DDAS	542	AMPS	0	3.4	40.0	41.0	41.5	42.3	43.0	43.6	43.9	0	0
W-1	DDAS	100	KW	NOT AVAILABLE.										
W-2	DDAS	101	KW	NOT AVAILABLE.										
W-3	DDAS	102	KW	NOT AVAILABLE.										

A-5

AEROJET GENERAL CORPORATION
SNAP-8 TEST DATA SHEET

PAGE [illegible] OF [illegible]

DATE ____________
ITEM [illegible]
TEST No. [illegible]
W.O. No. [illegible]

TEST ENGINEER BAILEY/M [illegible] TECHNICIAN CHADBOURNE

BLDG. [illegible] TEST BAY ____ LOOP DESIGNATION SMI TEST BACK FL[illegible]

TIME START 1410 TIME STOP 735 DURATION: hr 3 min 25 sec

PURPOSE RELEASE FLOW TEST OF TA SEAL COOLANT ANNULUS FOR ΔP

REMARKS ____________

Time	UNITS	1705	1710	715	720	725	1730	735
PUMP SKT IN PRESS. PPS-P-19	psia	3.1	3.3	3.2	3.3	3.3	3.3	
PUMP DISCH PRESS - PPD P-21	psia	[illegible]	49.5	49.8	50.3	50.0	49.8	
PRESS TA COOLANT OUT PTCO	psia	4.2	4.0	4.1	4.1	4.0	4.[illegible]	
PRESS TA COOLANT IN. P-9	psia	30.0	28.5	28.5	28.3	28.2	28.3	
TEMP [illegible] SUPPLY T-30	°F	208	210	208	207	[illegible]	210	
FLOW RATE F-2 lb/hr	lb/hr	1400	1400	1400	1400	1400	1400	
PRESS [illegible] SUPPLY - P-8	psia	[illegible]	35	35.2	35.2	35.2	35.0	
[illegible] SUPPLY P-11	psia	4.2	4.0	4.0	4.0	4.[illegible]	[illegible]	

A-6

APPENDIX B

CALCULATIONS BASED ON TEST DATA

THE BEARING AND SLINGER LOSSES AND THE ALTERATOR LOSSES MAY BE CALCULATED FROM THE TEMPERATURES AND FLOWS IN THE L/C SYSTEM.

BEARING AND SLINGER LOSSES - DESIGN INLET PRESSURE

TURBINE ANT-DRIVE:

$\dot{W}_{IN} = 215 \text{ lb/hr}$

$T_{IN.} = 230°F$

$\dot{W}_{OUT_1} = 157 \text{ lb/hr AT } 254°F$

$\dot{W}_{OUT_2} = 58 \text{ lb/hr AT } 270°F$

ASSUME C_p = CONSTANT = 0.395

$\therefore \quad \dot{Q}_1 = \dot{W} C_p \Delta T = .395[157(254-230) + 58(270-230)]$

$\dot{Q}_1 = \underline{2410 \text{ Btu/hr.}}$

$P_1 = \underline{\underline{.703 \text{ KW}}}$

TURBINE DRIVE:

$\dot{W}_{IN} = 200\ lb/hr$

$T_{IN} = 230\ °F$

$\dot{W}_{OUT_1} = 146\ lb/hr\ @\ 240°F$

$\dot{W}_{OUT_2} = 54\ lb/hr\ @\ 266°F$

$\dot{Q}_2 = (146 \times 10 + 54 \times 36).395 = \underline{1345\ Btu/hr}$

$P_2 = \underline{\underline{.394\ KW}}$

ALTERNATOR DRIVE:

$\dot{W}_{IN} = 153\ lb/hr\ @\ 230°F$

$\dot{W}_{OUT_1} = 63\ lb/hr\ @\ 270°F$

$\dot{W}_{OUT_2} = 90\ lb/hr\ @\ 251°F$

$\dot{Q}_3 = (63 \times 40 + 90 \times 21) \times .395 = \underline{1743\ Btu/hr.}$

$P_3 = \underline{\underline{.490\ KW}}$

ALTERNATOR ANTI-DRIVE:

$\dot{W}_{IN} = 760 - 215 - 200 - 153 = 192$ lb/hr.

ASSUME $\dot{W}_{OUT_1} = 79$ lb/hr @ 272°F

$\dot{W}_{OUT_2} = 113$ lb/hr @ 252°F

$\dot{Q}_4 = (79 \times 42 + 22 \times 113) \times .395 = \underline{2300 \text{ Btu/hr.}}$

$P_4 = \underline{\underline{.675 \text{ KW}}}$

THE TOTAL BEARING LOSSES WILL BE

$P_{LOSS\ BEARING\ \&\ SLINGERS} = .703 + .394 + .490 + .675$

$P_{L_{B\&S}} = \underline{\underline{2.262 \text{ KW}}}$

BEARING & SLINGER LOSSES – L/C INLET PRESSURE = 70PSIA

TURBINE ANTIDRIVE:

$\dot{W}_{IN} = 300 \text{ lb/hr} \ @ \ 237°F$

$\dot{W}_{OUT_1} = 185 \text{ lb/hr} \ @ \ 255°F$

$\dot{W}_{OUT_2} = 115 \text{ lb/hr} \ @ \ 250°F$

$\dot{Q}_1 = (185 \times 18 + 115 \times 13).395 = \underline{1910 \text{ Btu/hr}}$

$P_1 = \underline{.56 \text{ KW}}$

TURBINE DRIVE:

$\dot{W}_{IN} = 275 \text{ lb/hr} \ @ \ 237°F$

$\dot{W}_{OUT_1} = 210 \text{ lb/hr} \ @ \ 254°F$

$\dot{W}_{OUT_2} = 65 \text{ lb/hr} \ @ \ 262°F$

$\dot{Q} = (210 \times 17 + 65 \times 25).395 = \underline{1195 \text{ Btu/hr}}$

$P_2 = \underline{.35 \text{ KW}}$

ALTERNATOR DRIVE:

$\dot{W}_{IN} = 220$ lb/hr. @ 237°F

$\dot{W}_{OUT_1} = 90$ lb/hr. @ 248°F

$\dot{W}_{OUT_2} = 130$ lb/hr @ 263°F

$\dot{Q}_3 = (9 \times 11 + 130 \times 26) \times \underline{\cancel{.369 \text{ Btu/hr}}}^{\,.395} = \underline{1725 \text{ Btu/hr}}$

$P_3 = .505$ KW

ALTERNATOR ANTIDRIVE:

$\dot{W}_{IN} = 215$ lb/hr @ 237°F

$\dot{W}_{OUT_1} = 87$ lb/hr. @ 257°F

$\dot{W}_{OUT_2} = 128$ lb/hr @ 274°F

$\dot{Q}_4 = (87 \times 20 + 128 \times 37) .395 = 3480$

$P_4 = 1.015$ KW

TOTAL BEARING & SLINGER LOSSES:

$P_{B\&S} = .56 + .35 + .505 + 1.015 = \underline{\underline{2.43 \text{ KW}}}$

ALTERNATOR LOSSES

THE ALTERNATOR COOLANT FLOW IS

$$W_C = 1335 \text{ lb/hr.} \quad @ \quad P_{He_{IN}} = 40 \text{ psiA}$$

THE INLET TEMPERATURE IS

$$T_{IN} = 230°F$$

THE OUTLET TEMPERATURE IS

$$T_{OUT} = 236°F$$

$$\therefore Q = \dot{w} C_p \Delta T = 1335 \times .395 \times 6 = 3160 \text{ Btu/hr}$$

$$P = .916 \text{ KW}$$

ASSUMING THE ALTERNATOR OUTPUT WAS 13.5 KW,

THE ALTERNATOR EFFICIENCY IS

$$\eta_{ALT.\ ELECT.} = \frac{13.5}{14.42} = .935$$

FOR 1.165 KW BEARING & SLINGER LOSSES

$$\eta_{ALT.\ TOTAL} = .866$$

THE ALTERNATOR EFFICIENCY MAY BE RE-EVALUATED ON THE BASIS OF THE TOTAL G/C OUTLET TEMPERATURE AND THE LUBRICANT OUTLET TEMPERATURE. THIS TEMPERATURE DERIVATION SHOWS A TEMPERATURE RISE IN THE ALTERNATOR OF

$$\Delta T_{ALT} = 6.4°F$$

THE ALTERNATOR HEAT REJECTION IS

$$P_L = \frac{6.4}{4} \times .62 = .99 \, KW$$

THE ALTERNATOR EFFICIENCY IS THEREFORE

$$\eta_{ALT\,ELECT} = \frac{13.5}{14.4} = .93$$

$$\eta_{ALT.} = \frac{13.5}{15.57} = .867$$

A THIRD METHOD OF EVALUATING THE ALTERNATOR EFFICIENCY IS THROUGH THE TURBINE POWER OUTPUT.

$$P_{TURBINE} = \frac{\eta \dot{w} H_{ad}}{550} = \frac{.44 \times .515 \times 57200}{550} = 23.8 \text{ HP}$$

$$P_{TURBINE} = 17.7 \text{ KW}$$

SUBTRACTING 1.1 KW FOR THE TURBINE BEARINGS AND 1 KW FOR THE RUBBING SEALS

$$P_{ALT_{IN}} = 15.6 \text{ KW}$$

$$\eta_{ALT} = .865$$

TAKING THE BEARING & SLINGER LOSSES INTO ACCOUNT

$$\eta_{ALT_{ELECT.}} = .935$$

EXTRAPOLATION OF TEST DATA TO DESIGN CONDITIONS
FOR SPACE SEAT HEAT EXCHANGER PRESSURE DROP.

ASSUME $\Delta P = f \frac{L}{D} \frac{\gamma V^2}{2g}$

$$f = \frac{64}{Re} = \frac{64}{\frac{VD\gamma}{\mu}}$$

$$\Delta P = \frac{64\mu}{VD\cancel{\gamma}} \frac{L}{D} \cancel{\gamma} \frac{V^2}{2g}$$

$$\frac{\Delta P_1}{\Delta P_2} = \frac{\mu_1 V_1}{\mu_2 V_2} = \frac{\mu_1 \dot{W}_1}{\mu_2 \dot{W}_2}$$

$\mu_{210°F} = 17$ lb/ft hr

$\mu_{230°F} = 13$ lb/ft hr

THE DESIGN CONDITIONS OF THE HEAT EXCHANGER ARE

$T = 210°F$

$\dot{W} = 1600$ lb/hr.

THE TEST CONDITION IS

$T = 230°F$

$\dot{W} = 1335 \text{ lb/hr}$

$\Delta P = 24 \text{ psi}$

THE EXTRAPOLATED PRESSURE DROP IS THEN

$$\Delta P' = 24 \times \frac{12}{13} \times \frac{1600}{1335} = \underline{\underline{37.6 \text{ psi}}}$$

TURBINE EFFICIENCY

THE TURBINE EFFICIENCY IS

$$\eta = \frac{\Delta T_{ACT}}{\Delta T_{THEO.}}$$

$$\Delta T_{THEO.} = T_{IN}\left[1 - \left(\frac{P_{EX}}{P_0}\right)^{\frac{K-1}{K}}\right]$$

$$\Delta T_{THEO} = [333+460]\left[1 - \left(\frac{15}{77}\right)^{.286}\right]$$

$$\Delta T_{THEO} = 793\left[1 - .1946^{.286}\right] = 793[1 - .626]$$

$$\Delta T_{THEO.} = 297°F$$

THE MEASURED EXHAUST TEMPERATURE IS 202°F,
THE ACTUAL ΔT IS THEREFORE

$$\Delta T_{ACT} = 333 - 202 = 131°F$$

THE TURBINE AERODYNAMIC EFFICIENCY IS THEN

$$\eta_T = \frac{131}{297} = .442$$

APPENDIX C

THRUST BALANCER AND INTERSTAGE SEAL LEAKAGE ESTIMATE

THRUST BALANCER LEAKAGE

THE THRUST BALANCER DIAMETER IS

$$D = 2.09''$$

THE CLEARANCE ON THE THRUST BALANCER IS

$$\delta = .005''$$

THIS YIELDS A LEAKAGE AREA OF

$$A_{LEAK} = \pi D \delta = 3.14 \times 2.09 \times .005 = .0328 \text{ IN}^2$$

THIS IS IN CONTRAST TO THE SECOND STAGE NOZZLE AREA OF

$$A_{t_2} = .489 \text{ IN}^2$$

$$\% \text{ LEAK} = \frac{C_f}{\varphi_N} \frac{.0328}{.489} = C_f \times .07$$

ASSUME THE FOLLOWING:

$$C_{d_{LABYRINTH}} = .4$$

ECCENTRICITY FACTOR ≈ 2

$$C_f = C_d \times \text{ECCENTRICITY FACTOR} = .8$$

THE THRUST BALANCER LEAKAGE IS THEN

$$\% \text{ LEAK} = .8 \times .07 = .056$$

ASSUMING A TOTAL FLOW OF .5 lb/sec., THE LEAKAGE FLOW WOULD BE

$$\dot{W}_{LEAK} = .056 \times 0.5 = \underline{\underline{.028 \text{ lb/sec.}}}$$

THE ABOVE LEAKAGE IS BASED ON THE ASSUMPTION THAT THE LABYRINTH IS ECCENTRICALLY LOCATED ON THE SHAFT. IF THE LABYRINTH IS CONCENTRIC WITH THE SHAFT, THE LEAKAGE WOULD BE REDUCED TO

$$\dot{W}'_{LEAK} = \tfrac{1}{2}\dot{W}_{LEAK} = .014 \text{ lb/sec.}$$

INTERSTAGE LABYRINTH LEAKAGE ESTIMATE

ASSUME THE DIAMETER TO BE 1.4" AND THE CLEARANCE TO BE .010". THE LEAKAGE AREA IS THEN

$$A_{LEAK} = \pi D \delta = 3.14 \times 1.4 \times .010 = \underline{.044 \text{ IN}^2}$$

ASSUME A LABYRINTH COEFFICIENT OF $\varphi = .4$ WITH AN ECCENTRICITY FACTOR OF 2. ALSO ASSUME THE NOZZLE COEFFICIENT TO BE $\varphi_N = .96$. THE PERCENTAGE LEAKAGE IS THEN

$$LEAK_{I-II_E} = \frac{.8 \times .044}{.96 \times .489} \times 100 = 7.5\%$$

$$LEAK_{II-III_E} = \frac{.8 \times .044}{.96 \times .962} \times 100 = 3.8\%$$

$$LEAK_{III-IV_E} = \frac{.8 \times .044}{.96 \times 1.85} \times 100 = 2\%$$

IF THERE WERE NO ECCENTRICITY OF THE LABYRINTH, THE RESPECTIVE LEAKAGES WOULD BE

$$LEAK_{I\text{-}II_{NE}} = 3.8\%$$

$$LEAK_{II\text{-}III_{NE}} = 1.9\%$$

$$LEAK_{III\text{-}IV} = 1\%$$

THE ACTUAL LEAKAGE RATE IS PROBABLY BETWEEN THESE TWO EXTREME FACTORS.

APPENDIX D

ERROR ESTIMATION OF TEST RESULTS

ERROR ANALYSIS

AN ERROR ANALYSIS IS REQUIRED ON THE TEST RESULTS TO DETERMINE THE MOST PROBABLE VALUES. FOR THIS ANALYSIS, ASSUME THE FOLLOWING ACCURACIES (SEE MEMO 374:64:0206)

$\dot{W}_{N_2}$ - ± 2%

P - ± 2%

T - ± 1½%

$\dot{W}_{ET-378}$ - ± 4%

A. BEARING & SLINGER LOSSES:

$$\frac{Q}{C_p} = \dot{W}\Delta T = \dot{W}(T_1 - T_2)$$

THE STANDARD ERROR FOR ΔT IS

$$\alpha = \sqrt{\alpha_1^2 + \alpha_2^2}$$

$$\alpha_T \approx \sqrt{2 \times (.015 \times 230)^2}$$

$$\alpha_T \approx 4.88°$$

$$\alpha_{Q/C_p} = \sqrt{.08^2 \times 30^2 + 4.88^2 \times 200^2} \simeq 976$$

USING THE C_p VALUE FOR ET-378 FROM THE SNAP-8 REFERENCE DOCUMENT AND ASSUMING THAT NO ERROR IS ASSOCIATED WITH THIS VALUE (ACCURACY OF THIS DATA CANNOT BE ASSESSED), THE ERROR OF THE POWER CALCULATION IS

$$P' = P \pm 976 \times \frac{.395}{3415} = \underline{\underline{P \pm .113 \text{ KW}}}$$

B. TA SPACE SEAL PRESSURE DROP

$$\Delta P = P_1 - P_2$$

$$P_1 = 40 \pm .8 \text{ PSI}$$

$$P_2 = 16 \pm .32 \text{ PSI}$$

$$\alpha_{\Delta P_{HE}} = \sqrt{.8^2 + .32^2} = .86 \text{ PSI}$$

$$\therefore \Delta P'_{HE} = \Delta P \pm .86 \text{ PSI}$$

C. ALTERNATOR EFFICIENCY

METHOD 1

$$P = K\,\dot{W}\Delta T$$

$$\alpha_T \simeq 5°F$$

$$\alpha_{\%} \approx 5 \times 1335 = 7700$$

$$P' = P \pm .89KW$$

OR APPROXIMATELY $\pm 6\%$

METHOD 2

$$P = K\dot{W}\Delta T$$

$$\Delta T_2 = \frac{(\dot{W}_c + \dot{W}_L) \times \overset{\Delta T}{\cancel{\Delta T}} - \dot{W}_L \Delta T}{\dot{W}_c}$$

$$\Delta T = \frac{(\overset{\sim 5\%}{\dot{W}_c + \dot{W}_L})\Delta T - \overset{\sim 5\%}{\dot{W}_L \Delta T}}{W_c \sim 4\%}$$

ERROR $\simeq$ 8%

D. TURBINE EFFICIENCY

$$\alpha_T = \sqrt{5^2 + 3^2} = 5.8^\circ$$

$$Q/c_p = \dot{W} \Delta T \ast$$

$$E = \sqrt{.058^2 + .02^2} = 6.2\%$$

APPENDIX E

CALCULATION OF THEORETICAL TURBINE PERFORMANCE ON THE BASIS OF THE TEST CONDITIONS FOR N_2

TURBINE PERFORMANCE PREDICTION

ASSUME THE FOLLOWING CONDITIONS:

$P_o = 75$ psia
$T_o = 333°F = 793°R$
$T_{ex} = 202°F = 562°R$
$\dot{W} = .515$ lb/sec.
$P_{ex} = 15$ psia
TURBINE NOZZLE EXIT AREAS
$A_1 = .002585$ ft²
$A_2 = .00340$ ft²
$A_3 = .00658$ ft²
$A_4 = .01285$ ft²
NOZZLE FLOW COEFFICIENTS
$\varphi_1 = .96$
$\varphi_2 = .97$
$\varphi_3 = .96$
$\varphi_4 = .97$

ASSUME $P_{1ex} = 60$ psia

FOR $K = 1.4$ FROM NACA REPORT 1135

$$@ \frac{P_{1ex}}{P_o} = \frac{60}{75} = .8$$

$M = .573$
$P/P_t = .852$
$T/T_t = .938$
$V/a_K = .608$

THE DENSITY AT THE TURBINE INLET IS

$$\rho_{o_1} = \frac{P_o}{RT_o} = \frac{75 \times 144}{55.2 \times 793} = .247 \text{ lb/ft}^3$$

THE SONIC CONDITIONS FOR THE FIRST STAGE NOZZLES ARE

$$T_{*_1} = .833\, T_{o_1} = 660$$

$$a_* = 49.9\sqrt{T_*} = 1283 \text{ ft/sec.}$$

THE NOZZLE EXHAUST VELOCITY IS THEN

$$V_1 = .608\, a_* = 780 \text{ ft/sec.}$$

THE NOZZLE EXHAUST DENSITY IS

$$\rho_1 = .852\, \rho_{o_1} = .21 \text{ lb/ft}^3$$

THE NOZZLE FLOW IS THEN

$$\dot{W}_1 = \varphi\, \rho_1 A_1 V_1 = .96 \times .21 \times .002585 \times 780$$

$$\dot{W}_1 = .406 \text{ lb/sec.} \quad (\text{TOO LOW})$$

TRY $P_{1_M} = 58$ psia

@ $\frac{P_{ex_1}}{P_{o_1}} = \frac{58}{75} = .774$

$M = .617$

$\rho/\rho_t = .833$

$T/T_t = .930$

$V/a_* = .651$

THE NEW NOZZLE VELOCITY IS

$V_1 = .651 \times 1283 = 837$ '/sec.

THE NEW NOZZLE EXIT DENSITY IS

$\rho_1 = .833 \times .247 = .206$ lb/ft³

THE NEW NOZZLE FLOW IS THEN

$\dot{W}_1 = \phi \rho_1 A_1 V_1 = .96 \times .206 \times .002585 \times 837$

$\dot{W}_1 = .428$ lb/sec.

TRY $P_{ex_1} = 55$ psia

$$@ \frac{P_{x_1}}{P_{o_1}} = \frac{55}{75} = .734$$

$M = .68$

$\rho/\rho_t = .802$

$T/T_t = .915$

$V/a_* = .713$

THE NEW NOZZLE VELOCITY IS

$$V_1 = .713 \times 1283 = 915 \text{ ft/sec.}$$

THE NEW NOZZLE EXIT DENSITY IS

$$\rho_1 = .802 \times .247 = .1995$$

THE NEW FLOW IS

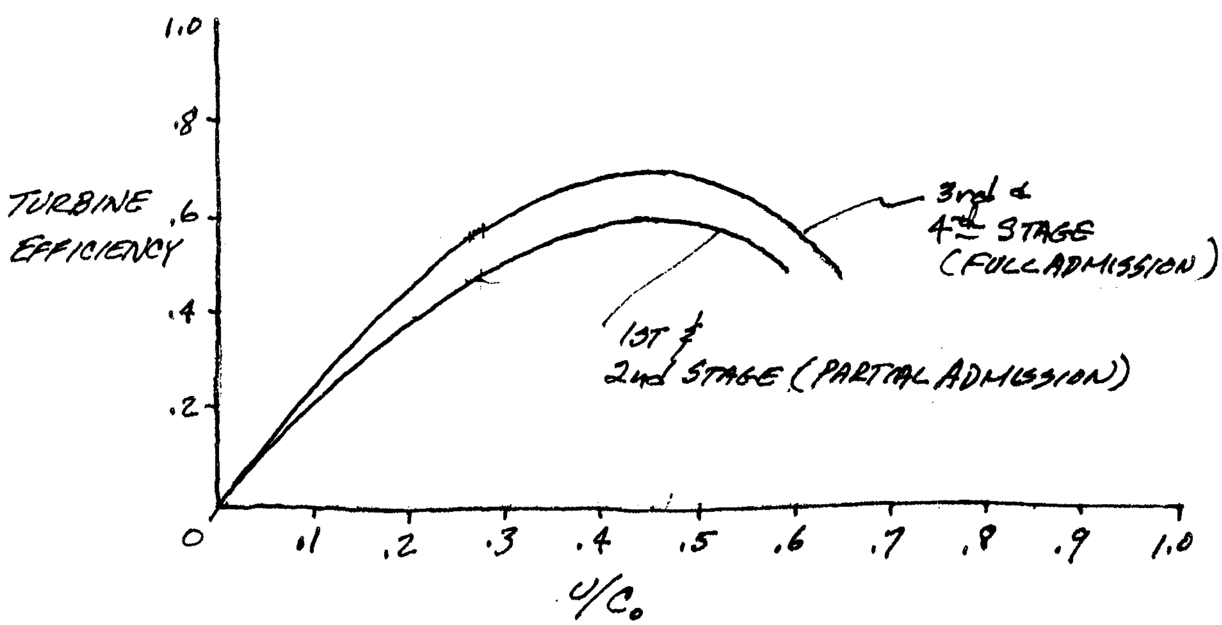
$$\mathring{W}_1 = .96 \times .1995 \times .002585 \times 915$$

$$\mathring{W}_1 = .453$$

THE EFFICIENCY OF THE STAGE MAY BE ESTIMATED. ASSUME A TURBINE TIP SPEED OF 267 ft/sec. THE TIP SPEED/SPOUTING VELOCITY RATIO IS THEN

$$U/C_o = U/V_1 = \frac{267}{915} = .292$$

ASSUME THE FOLLOWING TURBINE EFFICIENCY VS U/C_o RELATION IS VALID



ASSUME THE FIRST STAGE EFFICIENCY TO BE

$$\eta_{t_1} = 50\%$$

THE TEMPERATURE AT THE SECOND STAGE INLET IS THEN

$$T_{o_2} = T_{o_1} - \eta_{t_1} \Delta T_1 = 793 - .5[793 - 725]$$

$$T_{o_2} = 759°R$$

SECOND STAGE

ASSUME A FIRST STAGE AXIAL EXIT VELOCITY

OF

$$V_{AX_1} = \sin\alpha_1 V_1 \phi_{N_1} \phi_{R_1} = 915 \times .96 \times .8 \times .293$$

$$V_{ax_1} = 220 \text{ ft/sec.}$$

$$\frac{V^2}{2g} = \frac{220^2}{64.4} = 752 \text{ ft.}$$

$$P = \frac{752}{} \text{ ft} \times .1995 \times \frac{725}{759} \frac{\text{lb}}{\text{ft}^3} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2}$$

$$P = 1 \text{ psi}$$

$$\therefore P_{o_2} = 55 + 1 = 56 \text{ psi}$$

ASSUME $P_{ex_2} < 29.6$ psi OR SECOND STAGE NOZZLE IS SONIC. (TRY 27 PSIA)

THE DENSITY OF THE GAS AT THE SECOND STAGE INLET IS

$$\rho_{o_2} = \frac{P_{o_2} \times 144}{R\,T_{o_2}} = \frac{56 \times 144}{55.2 \times 759} = .1925 \text{ lb/ft}^3$$

FOR A SONIC NOZZLE

$\rho/\rho_t = .634$

$V = a_* = 49.9\sqrt{T_*} = 49.9\sqrt{632}$

$V = 1253$

THE FLOW RATE IS THEN

$\dot{W}_2 = \rho/\rho_t A_2 V_2 = .97 \times .122 \times .00340 \times 1253$

$\dot{W}_2 = .505$ lb/sec.

REITERATE FOR $P_{ex_1} = 51$ psiA, $P_{o_2} = 52$ psiA

FIRST STAGE

$@ \left(P_{ex}/P_o\right)_1 = \frac{51}{75} = .68$

$M = .763$

$\rho/\rho_t = .762$

$T/T_t = .896$

$V/a_* = .791$

$\rho_1 = .762 \times .247 = .188 \; lb/ft^3$

$V = .791 \times 1283 = 1015 \; ft/sec.$

$\dot{W}_1 = .96 \times .188 \times .002585 \times 1015$

$\dot{W}_1 = \underline{.474 \; lb/sec.}$

THE U/C_0 RATIO IS

$$U/C_0 = \frac{267}{1015} = .263$$

THE TURBINE EFFICIENCY IS $\underline{\eta_1 = .46}$

THE TEMPERATURE AT THE SECOND STAGE INLET IS THEN

$$T_{0_2} = 793 - .46[793 - 710]$$

$$T_{0_2} = 755 \, °R$$

<u>SECOND STAGE</u>

THE SECOND STAGE INLET DENSITY IS

$$\rho_{0_2} = \frac{52 \times 144}{55.2 \times 755} = .1795$$

E-8

ASSUME SECOND STAGE NOZZLE IS CHOKED, OR

$$P/P_t = .634$$

$$V = a_* = 49.9\sqrt{630} = 1253 \text{ ft/sec.}$$

THE FLOW RATE IS THEN

$$\dot{w}_2 = .97 \times .114 \times .0034 \times 1253$$

$$\dot{w}_2 = \underline{\underline{.472 \text{ lb/sec.}}}$$

ASSUMING THAT THE EXHAUST PRESSURE IS $\underline{27 \text{ PSIA}}$

FOR THE SECOND STAGE, THE EXIT VELOCITY WILL BE

@ $P/P = .52$ $\quad V/a_* = 1011$

$$T/T_t = .830$$

$$V = 1266 \text{ ft/sec}$$

THE U/C_o RATIO IS THEN

$$U/C_o = \frac{267}{1266} = .211$$

THE TURBINE EFFICIENCY IS

$$\eta_{t_2} = \underline{\underline{.38}}$$

3rd STAGE

THE INLET TEMPERATURE TO THE THIRD STAGE IS

$$T_{0_3} = T_{0_2} - \eta_{t_2}\left[T_{0_2} - T_2\right]$$

$$T_{0_3} = 755 - .38\left[755 - 627\right] = 706\,°R$$

THE DENSITY AT THE THIRD STAGE INLET IS

$$\rho_{0_3} = \frac{27 \times 144}{56.2 \times 706} = .0997\ \text{lb/ft}^3$$

ASSUME A THIRD STAGE EXIT PRESSURE OF

$$P_{ex_3} = 18\ \text{PSIA}$$

@ $$\left(\frac{P}{P_0}\right)_3 = \frac{18}{27} = .667$$

$$M = .783$$

$$\rho/\rho_t = .749$$

$$T/T_t = .891$$

$$V/a_* = .809$$

E-10

$$T_{*_3} = .833 \times 706 = 588\,°R$$

$$a_{*_3} = 1210 \text{ ft/sec.}$$

$$V_3 = 978 \text{ ft/sec}$$

$$\rho_3 = .749 \times .0997 = .0746$$

THE FLOW IS THEN

$$\dot{W}_3 = .96 \times .0746 \times .00658 \times 978 = .462 \text{ lb/sec.}$$

THE THIRD STAGE U/C₀ RATIO IS

$$\left(U/C_0\right)_3 = \frac{267}{978} = .273$$

THE EFFICIENCY IS THEN

$$\eta_{t_3} = 56\%$$

4TH STAGE

THE INLET TEMPERATURE TO THE FOURTH STAGE IS

$$T_{0_4} = T_{0_3} - \eta_{t_3}\left[T_{0_3} - T_3\right]$$

$$T_{0_4} = 706 - .56\left[706 - 629\right]$$

$$T_{0_4} = 663\,°R$$

E-11

THE FOURTH STAGE INLET DENSITY IS

$$\rho_{0_4} = \frac{18 \times 144}{53.2 \times 663} = .0708 \text{ lb/ft}^3$$

$$@ \left(\frac{P}{P_0}\right)_4 = \frac{15}{18} = .833$$

$M = .516$

$\rho/\rho_t = .879$

$T/T_t = .95$

$V/a_* = .550$

THE SONIC VELOCITY IS

$T_* = .833 \times 663 = 552\,°R$

$a_* = 1174$ ft/sec.

$V_4 = 645$ ft/sec.

$\rho_4 = .0622$ lb/ft^3

THE FLOW IS THEN

$$\dot{W}_4 = .97 \times .0622 \times .0128 5\times 645 = .50 \text{ lb/sec.}$$

REITERATE 3RD & 4TH STAGE FOR $P_{ex_3} = 17.5$ PSIA

$$@\left(P/P_0\right)_3 = \frac{17.5}{27} = .648$$

$$M = .812$$

$$\rho/\rho_t = .734$$

$$T/T_t = .883$$

$$V/a_* = .836$$

$$V_3 = .836 \times 1210 = 1011 \text{ ft/sec}$$

$$\rho_3 = .734 \times .0997 = .0732 \text{ lb/ft}^3$$

$$\dot{W}_3 = .96 \times .0732 \times .00658 \times 1011 = \underline{.468} \text{ lb/sec.}$$

$$\left(U/C_0\right)_3 = \frac{267}{1011} = .264$$

$$\eta_{t_3} = \underline{.55}$$

<u>4TH STAGE</u>

$$T_{0_4} = 706 - .55[706 - 624]$$

$$T_{0_4} = \underline{661°R}$$

THE FOURTH STAGE INLET DENSITY IS

$$\rho_{o4} = \frac{17.5 \times 144}{55.2 \times 661} = .069 \ lb/ft^3$$

$$@ \left(\frac{P}{P_o}\right) = \frac{15}{17.5} = .857$$

$M = .475$

$\rho/\rho_t = .895$

$T/T_t = .957$

$V/a_* = .509$

SONIC VEL. $T_* = .833 \times 661 = 550$

$a_{*4} = 1170 \ ft/sec$

$V_4 = 595 \ ft/sec.$

$\rho_4 = .0617 \ lb/ft^3$

$$\dot{W}_4 = .97 \times .0617 \times .01285 \times 595 = \underline{\underline{.458}} \ lb/sec.$$

THE U/C RATIO IS

$$\left(\frac{U}{C_o}\right)_4 = \frac{267}{595} = .45$$

THE TURBINE EFFICIENCY IS THEN

$$\eta_{t_4} = .70$$

THE TURBINE EXHAUST TEMPERATURE IS

$$T_{ex_4} = 661 - .7[661 - 633]$$

$$T_{ex_4} = 642°R = 182°F$$

ASSUME A 2.5% LABYRINTH LEAKAGE BETWEEN STAGES.

$$T_4 = .025 \times 755 + .975 \times 642 = 645°R$$

THE IDEAL HEAD AVAILABLE FOR ALL FOUR STAGES IS

$$H_{AD_{TOTAL}} = \frac{K}{K-1} RT_1 \left[1 - \left(\frac{P_4}{P_0}\right)^{\frac{K-1}{K}}\right]$$

$$H_{AD_{TOTAL}} = \frac{1.4}{1.4-1} 55.2 \times 793 \left[1 - \left(\frac{15}{75}\right)^{.286}\right]$$

$$H_{AD_{TOTAL}} = 56{,}500 \text{ ft}$$

$$\Delta T_{IDEAL} = 293°$$

THE OVERALL AERODYNAMIC EFFICIENCY OF THE TURBINE IS

$$\eta_{t_{OVERALL}} = \frac{\Delta T_{ACTUAL}}{\Delta T_{IDEAL}} = \frac{793-645}{293} = \frac{148}{293} = \underline{\underline{50.5\%}}$$

THE EXPECTED LEAKAGE THROUGH THE THRUST BALANCER IS (FROM APPENDIX C)

$$\dot{W}_{LEAK_{T.B.}} = 0.028 \text{ lb/SEC.}$$

THE TOTAL TURBINE FLOW IS THEN

$$\dot{W} = \frac{.47}{.975} + .028 = .482 + .028 = \underline{\underline{.51 \text{ lb/SEC.}}}$$

THE TURBINE EXHAUST TEMPERATURE IS

$$T_{EX_{OVERALL}} = \frac{.482 \times 645 + .028 \times 793}{.512}$$

$$= \frac{311 + 24}{.512} = 654°R = \underline{\underline{194°F}}$$

THE AERODYNAMIC EFFICIENCY, INCLUDING THRUST BALANCER LOSSES, IS

$$\eta_t = \frac{793-654}{293} = \frac{139}{293} = \underline{\underline{.475}}$$

SUMMARY OF THEORETICAL CALCULATIONS

	1ST STAGE	2nd STAGE	3rd STAGE	4TH STAGE
INLET PRESS, PSIA	75	52	27	17.7
INLET TEMP, °F	333°F	295°F	246°F	201°F
U/C	.263	.211	.264	.45
η - %	46	38	55	70

FLOW - .51 lb/SEC

$\eta_{\text{OVERALL AERODYNAMIC}}$ - 47.5%

Test Report
No. 395/64-00014
Supplement No. 1
25 August 1964

TAA TESTING IN GN_2S-1

TEST D-5-R-5 (SECOND TEST)

TEST REPORT SUPPLEMENT NO. 1

Prepared by:

C. S. Mah

C. S. Mah
Rotating Machinery Dept.

Approved:

E. Eber, Dept. Head
Rotating Machinery Dept.
SNAP-8 Division

Von Karman Center
AEROJET-GENERAL CORPORATION
Azusa, California

TABLE OF CONTENTS

I. SUMMARY

The TAA was tested for a second time in GN_2S-1 (Test D-5-R-5). The objective of the test was to determine the effect of temperature on the L/C system performance.

By increasing L/C temperature from 187°F to 220°F, the following changes occurred:

1. Turbine space seal heat exchanger pressure drop decreased approximately as a function of $1/Re^{.5}$.
2. Bearing lubricant flow increased from 750 lb/hr to 820 lb/hr.
3. Bearing outer race temperature increased about 23°F.
4. Bearing and slinger losses decreased from 4.2 kw to 3.7 kw (for all four bearings).

The turbine aerodynamic efficiency was η_t = 51-52%.

II. INTRODUCTION

TAA No. 1, Buildup No. 1 was tested a second time in GN_2S-1 on 5 June 1964. The objects of the tests were the determination of the effect of the lubricant/coolant temperature on the operation of the bearing/seal system, the alternator, and the TAA L/C system in general.

The test facility (GN_2S-1) was unchanged from the first test (Test D-5-R-3) except for a modification of the oil cooler plumbing. This modification consisted of changing the fluid flow in the tube-in-shell heat exchanger from water-shell/oil-tube to oil-shell/water-tube. The modification was necessary when it was discovered in the first test that the cooler, as it was plumbed, was not capable of keeping the L/C temperature below 230°F for steady-state operation of the TAA at 15 kw output.

The normal procedure was followed for the testing. The L/C inlet temperature was varied in steps in the range of temperatures between 220°F and the lowest temperature achievable with the oil cooler (187°F). Steady-state data were taken at 204°F, 193°F, 187°F, 220°F and the design temperature of 210°F. There were no unusual occurrences during testing. The test was continued for 1 hour 25 minutes (from 1815 hours to 1940 hours) until the specific test objectives were achieved. All the data were acceptable except for the flows indicated by the flow meters F9 and F11. These turbine meters were influenced by stray magnetic flux from the alternator.

III. TEST RESULTS

A. PRESSURE DROP OF TURBINE SPACE SEAL HEAT EXCHANGER

The results of the flow test on the turbine space seal heat exchanger are shown in Figure 8. The test consisted of keeping the coolant inlet pressure constant at 40 psia while varying the inlet temperature. The temperature range covered was from 187°F to 220°F; these temperatures resulted in flow rates from 1120 lb/hr to 1325 lb/hr. With the flows scaled to a reference value of 1300 lb/hr, the pressure drop through the space seal heat exchanger is 31 psi and 24.5 psi at respective ET-378 inlet temperatures of 187°F and 220°F.

B. BEARING-LUBRICANT FLOW

Data for the flow through the TAA bearing lubricant injectors were also taken at varying inlet temperatures and constant inlet pressure. The results, (see Figure 9), show that the flow increased with the increase in inlet temperature of the lubricant. For the range of test temperatures, (187°F to 220°F), the total lubricant flow varied from 750 lb/hr to 820 lb/hr. The design flow at an inlet temperature of 210°F is 800 lb/hr.

The lubricant through-flow for the TA bearings was about 70%; the lubricant through-flow for the AA bearings was about 30%. The difference is due to the fact that all of the incoming lubricant was directed on the TA bearings, whereas only 55% of the total inlet lubricant flow was directed on the AA bearings, with 45% of the total flow directed on the inboard slingers to dissipate the heat generated in the alternator rotor.

C. ALTERNATOR COOLING AND ALTERNATOR EFFICIENCY

The TAA tests were based on a steady-state condition defined on the basis of the L/C inlet and exit temperatures. This steady-state definition did not give a good reference for the alternator stator temperature at varying inlet coolant temperatures because of the massiveness (therefore high heat capacity) of the alternator. However, the data shows that the stator hot spot temperature in the alternator was about 350°F at the test conditions, which was at an alternator output of about 15 kw (unity p.f.) and at coolant temperatures of 187°F to 220°F. The hot spot temperature alarm for normal testing is set for 500°F.

The predicted alternator electrical efficiency based on the alternator acceptance tests in the range of 11 kw to 15 kw output is 88-91%. The efficiency calculated on the basis of the alternator coolant temperature rise for this same power range is 75-83%.

D. BEARING OUTER-RACE TEMPERATURE

The outer-race temperatures of the TAA bearings are shown in Figure 10. For the range of lubricant inlet temperatures tested, the range of resulting bearing outer-race temperatures is shown to be between 235°F and 275°F, with the bearing temperature increasing as the lubricant temperature is increased. The turbine bearings are shown to run 10-15°F cooler than the alternator bearings. The reason for the cooler TA bearings may have been due to more lubricant flow; or it may have been due to the fact that the AA bearing temperature was taken by a thermocouple separated from the bearing outer race by .070 in. of housing material, 0.030 in. electrical insulation, and 0-0.010 in. air gap; or it may have been due to both factors. The preferred operating temperature for these bearings is 250°F; the alarm for normal testing is set at 300°F.

Figure 11 shows two data points indicating the change in bearing temperature as the bearing through-flow is changed. No firm conclusions can be drawn from these two test points, but the indications are that the bearing temperature will vary inversely as the bearing through-flow in the range nears design (150 lb/hr) conditions. It should be noted that the two data points are not a result of a test specifically aimed at finding the bearing temperature as a function of lubricant flow, but that they are the natural consequence of any given L/C test.

E. BEARING AND SLINGER SEAL LOSSES

The bearing and slinger-seal losses may be calculated from the lubricant flows and the lubricant inlet and outlet temperatures. These losses are shown in Figure 12 for all the bearings and slingers, and for each of the turbine bearings and slingers and the alternator drive bearing and slingers. No loss data are available for the alternator anti-drive bearing because the turbine meters used for lubricant flow measurements of this bearing were influenced by stray magnetic flux from the alternator.

The results show that there is about 1 kw loss per bearing total of about 4 kw), with the slinger discharge pressure at about 6.1 psia. The total bearing and slinger losses decreased from 4.2 to 3.7 kw as the lubricant temperature was increased from 187 to 220 °F. The predicted loss per bearing at design operating conditions is 0.86 kw, or 3.54 kw for all four, at a slinger discharge pressure of 4.75 psia. Test D-5-R-3 had a total bearing and slinger loss of 2.54 kw at a slinger discharge pressure of 3.1 psia and a lubricant inlet temperature of 230 °F.

F. TURBINE POWER

The turbine efficiency may be calculated two ways. One is the comparison of the actual and isentropic temperature drop across the turbine; the other is based on the alternator output. On the basis of nitrogen temperature drops, the turbine efficiency is about 52%. On the basis of alternator output, the turbine efficiency is about 51%.

IV. DISCUSSION

The second TAA test (Test D-5-R-5) was performed without an incident, and the test results indicate that it was successful. The test data generally conform to the theoretical predictions and the results of the first test (Test D-5-R-3).

A. TURBINE SPACE SEAL HEAT EXCHANGER PRESSURE LOSS

In Figure 8, the pressure drop across the turbine space seal heat exchanger is seen to decrease as the coolant temperature is decreased. The cause of the pressure drop change can be directly traceable to the viscosity of the coolant. Using the Reynolds Number as a dimensionless parameter, it can be shown that the pressure drop is approximately proportional to the heat exchanger passage Reynolds Number to the 0.53 power. Since ΔP is proportional to the first power of the Reynolds Number in laminar flow and proportional to the 0.2 power of the Reynolds Number for well-developed turbulent flow, it can be concluded that the flow in the turbine space seal heat exchanger is partly laminar and partly turbulent. However, the theoretical calculations showed that the maximum Reynolds Number for Test D-5-R-8 was less than 700, indicating a probable laminar flow. Deviation from laminar flow can occur only if the space seal heat exchanger passages are not according to print and/or the coolant viscosity is much less than it is assumed. Most probably, both of these were contributing factors.

The test data indicate that the pressure drop across the turbine space seal heat exchanger is 26.3 psi at a coolant inlet temperature of 210°F and a flow of 1300 lb/hr. Extrapolating this on the basis that the flow friction factor is proportional to the Reynolds Number to the 0.53 power, the pressure drop of the turbine seal heat exchanger at design operating conditions (1600 lb/hr. at 210°F) would be about 33 psi. The theoretical design value is 20 psi; Test D-5-R-3 results showed a pressure drop of 43 psi at an ET-378 flow of 1825 lb/hr. and at a temperature of 230°F, or 34 psi at design conditions.

Considering the magnitude of the difference between the theoretical pressure drop and the actual pressure drop, and the relationship between the friction factor and the Reynolds Number; it may be definitely stated that the heat exchanger passage dimensions are not according to design. The deviation can be in the heat exchanger passage dimension as it was fabricated, or it can be the plugging of the passage by foreign matter during testing. The former is most probable.

In terms of heat transfer, the higher ET-378 coolant pressure loss will yield a better heat transfer coefficient. This better heat transfer coefficient will mean that the Hg liquid-vapor interface in the seal will be cooler. However, the position of the interface will not be changed; its position is determined only by the slinger discharge pressure.

B. BEARING LUBRICANT FLOW

The lubricant flow through the bearing lubricant injectors under the test conditions was at a Reynolds Number of less than 10. At these low Reynolds Numbers, flow through an orifice is directly proportional to the Reynolds Number. The test results (Figure 9) show that this is the case with the lubricant injectors.

The flow coefficients for the injectors were about 0.65, which is consistent with theoretical values. No true test coefficients can be obtained because the pressure drop across the bearing lubrication injectors was not directly measured.

C. ALTERNATOR COOLING AND ALTERNATOR EFFICIENCY

The alternator had a hot spot temperature of about 350°F during the tests. This is consistent with the design values as well as the alternator acceptance-test results.

The alternator efficiency obtained in Test D-5-R-5 is low. Through the range of variation of coolant temperatures, the D-5-R-5 test results are consistently 10% below the alternator acceptance-test results. However, considering that the D-5-R-5 test results are based on a coolant temperature difference, and a 1% error in the temperature readings can affect the test results up to 40%; the test results are acceptable.

D. OTHER RESULTS

The bearing outer-race temperatures and the bearing and slinger losses are consistent with the theoretical values as well as the results in Test D-5-R-3. The results showed that increasing the lubricant temperature increased the bearing outer-race temperature and decreased the bearing and slinger losses. It is desirable to have the bearings cool, but it is equally desirable to minimize the bearing and slinger losses. The two factors must be weighed against each other to optimize the lubricant inlet temperature. The 210°F chosen for design seems to be a good compromise.

The trend indicated in the changing of the bearing and slinger losses with the changing of controlled variables showed the slinger discharge pressure and the lubricant viscosity to be the most important functions. In changing the slinger discharge pressure from 3 to 6 psia, the increase in bearing and slinger losses is estimated to be 0.8 kw. In changing the lubricant temperature from 187 to 225°F, the ET-378 viscosity changes from 31.5 lb/ft-hr. to 13.5 lb/ft.-hr; this viscosity change is estimated to decrease the bearing and slinger losses by 0.9 kw.

The turbine aerodynamic efficiency for Test D-5-R-5 is between 51-52%. This is considerably higher than the 44% obtained from Test D-5-R-3, and is higher even than the estimated 47.5% theoretical value. A possible change between the two tests is the reduction of the mechanical face seal rubbing friction. Considering this and the effect of the probable instrumentation accuracy ($\eta \pm 3\%$), the results of the tests and the theory are compatible.

V. CONCLUSIONS

A. The pressure drop and flow in the turbine space seal heat exchanger indicated that the coolant passages are not to print, and that there is turbulence in the passages for the Test D-5-R-3 and -5 conditions.

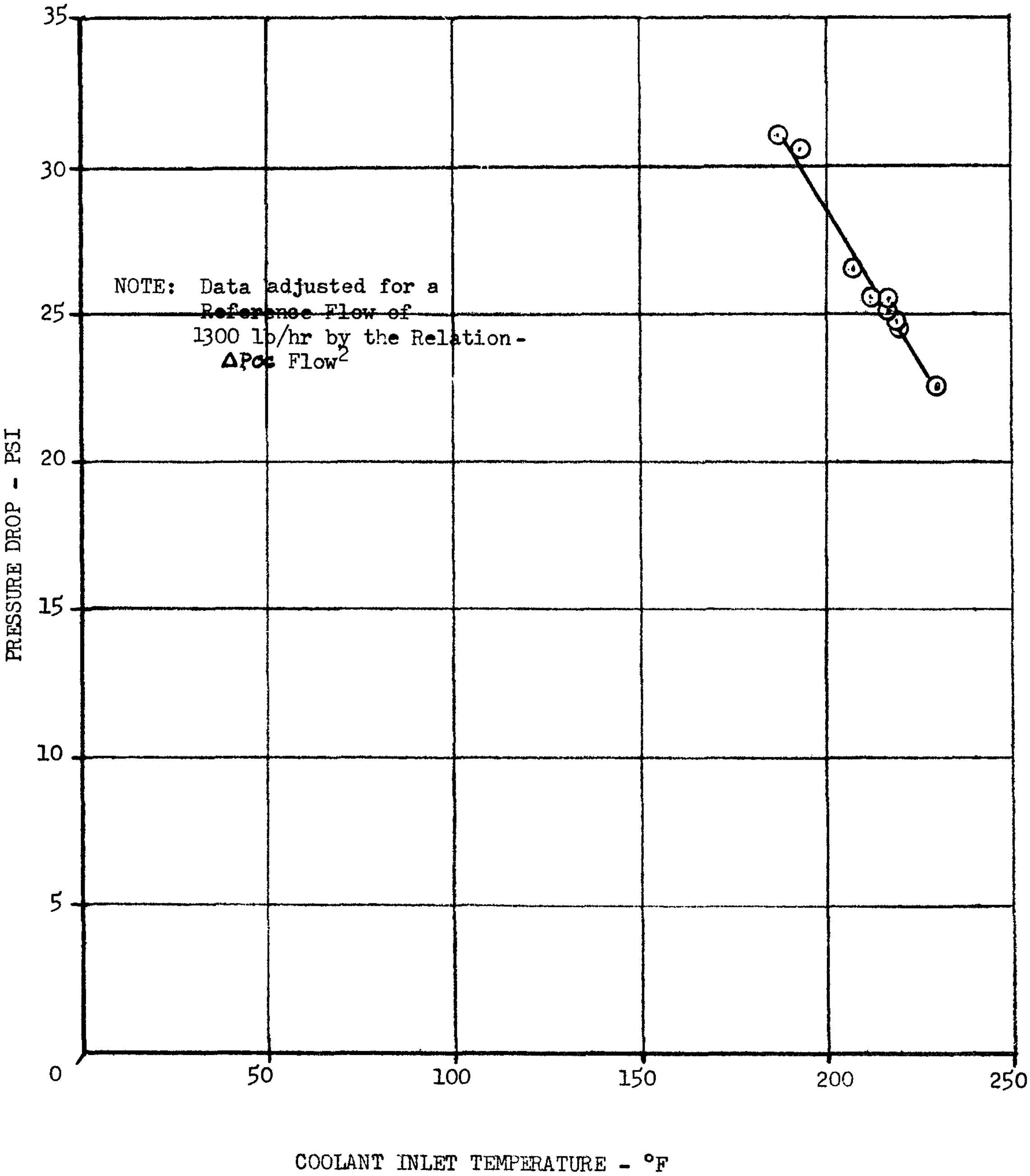
B. The bearing lubricant injectors flow in a low Reynolds Number regime; the test results are consistent with predicted values.

C. The bearing outer race temperature will increase with the increasing lubricant temperature and/or decreasing lubricant flow through the bearing.

D. The bearing and slinger losses decreased with increasing lubricant temperature and increased with increasing slinger discharge pressure.

E. The turbine efficiency is η_t = 51-52% (at U/C_o = .14 for N_2) for approximately 15 kw alternator output.

TURBINE SPACE SEAL HEAT EXCHANGER PRESSURE
DROP AT DIFFERENT COOLANT INLET TEMPERATURES
TAA #1, BUILDUP #1
TESTS D-5-R-3 and 5



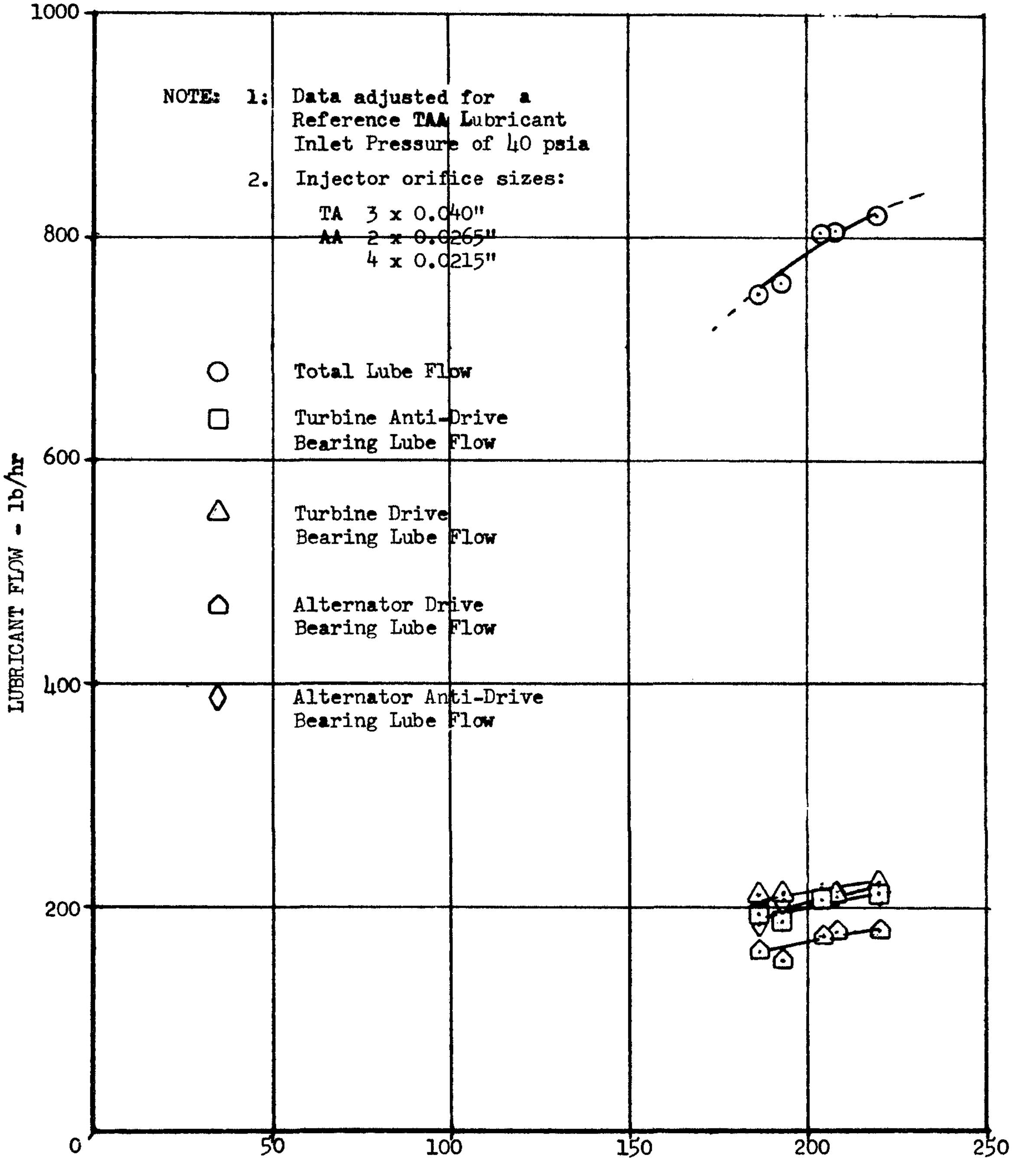
10-067-118

Figure 8

TAA LUBRICANT FLOW AT DIFFERENT LUBRICANT INLET TEMPERATURES

TAA #1, BUILD-UP #1

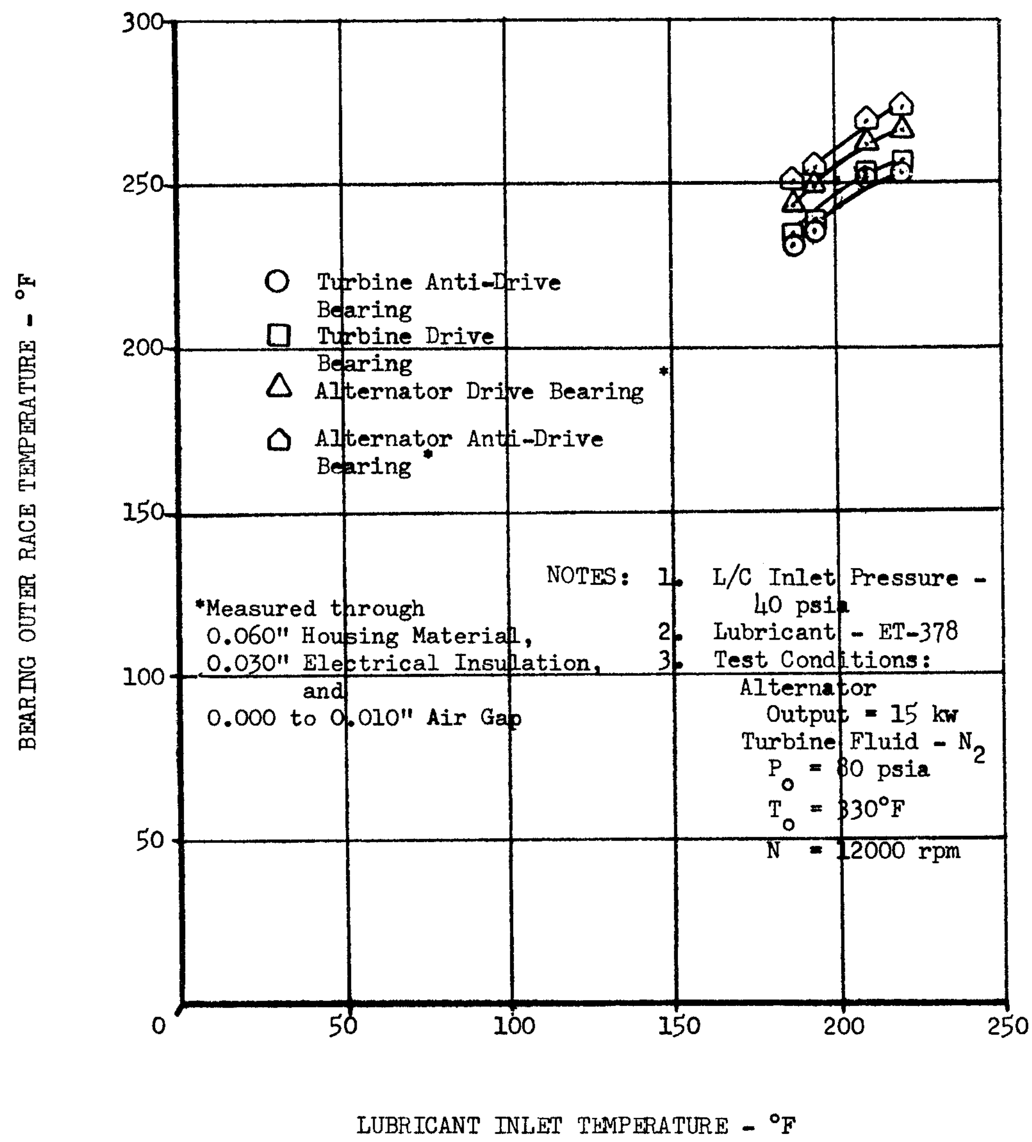
TEST D-5-R-5



10-687-118

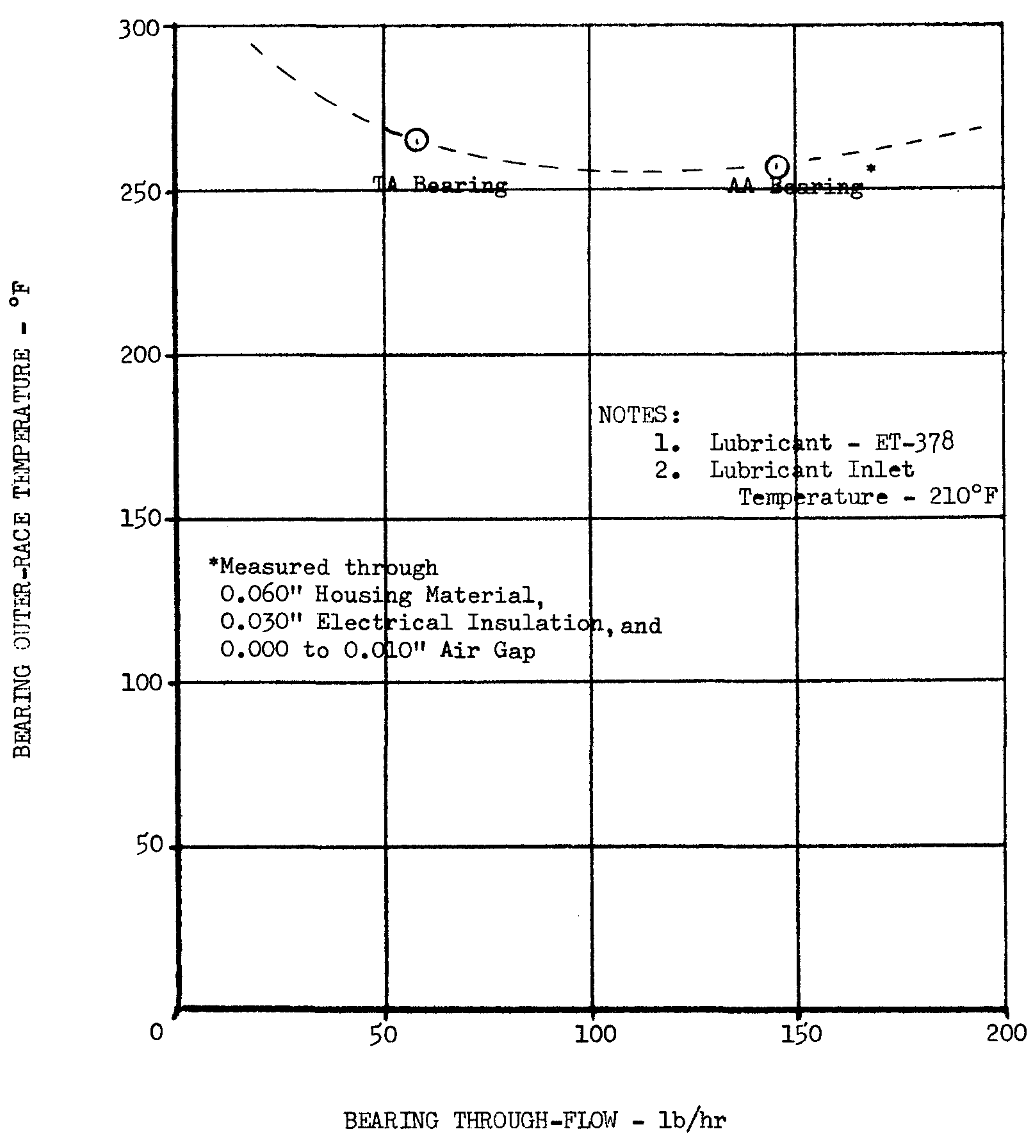
Figure 9

TAA BEARING OUTER-RACE TEMPERATURE
FOR DIFFERENT LUBRICANT INLET TEMPERATURES
TAA #1, BUILD-UP #1
TEST D-5-R-5

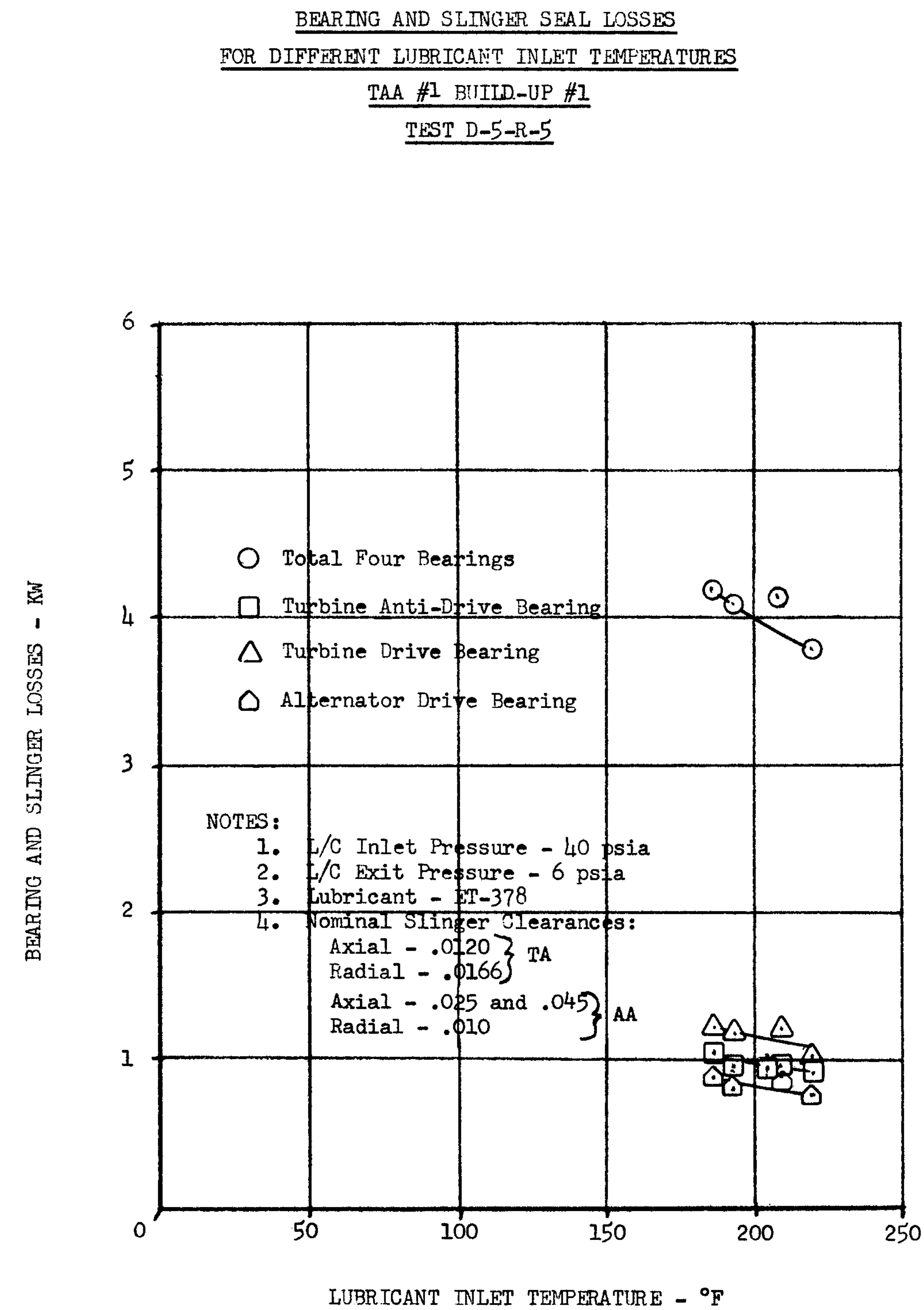


10-067-118

TAA BEARING OUTER-RACE TEMPERATURE
FOR DIFFERENT FLOWS THROUGH BEARING
TAA #1 BUILD-UP #1
TEST D-5-R-5



10-067-118



BEARING AND SLINGER SEAL LOSSES
FOR DIFFERENT LUBRICANT INLET TEMPERATURES
TAA #1 BUILD-UP #1
TEST D-5-R-5
Total Four Bearings
Turbine Anti-Drive Bearing
Turbine Drive Bearing
Alternator Drive Bearing
NOTES:
1. L/C Inlet Pressure - 40 psia
2. L/C Exit Pressure - 6 psia
3. Lubricant - ET-378
4. Nominal Slinger Clearances:
Axial - .0120
Radial - .0166
TA
Axial - .025 and .045
Radial - .010
AA
BEARING AND SLINGER LOSSES - KW
LUBRICANT INLET TEMPERATURE - °F
0
1
2
3
4
5
6
50
100
150
200
250

10-067-118-

[illegible] REQUESTED BY
TEST ENGR. PER DRR #10 AND #12.
[illegible]
[illegible]

SNAP-8 DATA REDUCTION SHEET

PRELIMINARY DATA
SNAP 8 DIVISION
REF. TM372:63-8-149
Calibration Corrected and Approved
Format for Internal Distribution Only

Prepared by	[illegible]
Checked by	[illegible]
Approved by	[illegible]
Date	3-5-64
Item	SNAP-8 TAD
Test No.	D-5-L-5
W. O. No.	2741-11-4023

TIME				1815	1845	1907	1925	1927	1928	1929	1930	1934	1938	1939	
FUNCTION	INSTR.	POSITION	UNITS												
D-1	DDAS	H.S.	INCHES	.0014	.0014	.0014	.0013	.0014	.0014	.0013	.0014	.0013	.0012	.0016	
E-1	REC.	8A-4	VOLTS	99	127.5	109X	110.5	111	111	111	111	111.5	106	107	
E-2	DDAS	055	VOLTS	98.2	107.2	108.6	110.1	110.3	110.7	109.2	110.6	111.0	106.4	106.8	
E-3	DDAS	056	VOLTS	97.9	106.8	108.0	109.9	110.2	110.7	109.0	110.3	110.8	106.1	106.5	
I-1	DDAS	542	AMPS	43.3	46.0	46.6X	47.2	47.2	47.4	47.3	47.4	47.6	45.9	45.8	
I-4	DDAS	545	AMPS	2.4	4.2	2.6	3.6	3.9	4.0	3.6	3.3	3.6	3.5	3.7	
I-5	DDAS	546	AMPS	1.2	1.3	1.4	1.4	1.4	1.4	1.2	1.2	1.3	1.1	1.1	
W-1	DDAS	100	KW	3.9	4.7	4.9	5.1	5.1	5.1	5.0	5.1	5.2	4.7	4.8	
W-2	DDAS	101	KW	4.0	4.7	4.9	5.0	5.0	5.1	5.0	5.1	5.1	4.7	4.8	
W-3	DDAS	102	KW	3.7	4.5	4.8	4.7	4.9	4.8	4.8	4.9	5.0	4.5	4.6	
Z-1 each sec	DDAS	000	RPM	12,030	12,150	12,120	12,090	12,390	12,480	12,840	12,870	12,810	13,050	13,020	
Z-2 continuous	REC	7B	RPM	11,820	12,120	11,970	12,120	12,090	12,360	12,360	12,660	12,720	12,540	12,900	
T-24	REC	9B-2	°F	244	235	231	250	250	251	251	253	254	251	251	
T-27	REC	6A	°F	245	238	234	252	253	254	255	257	256	253	254	
T-30	REC	24A	°F	204	193	187	217	217	218	219	220	212	208	207	
T-31	DDAS	237	°F	236	222	222	230	241	236	241	241	237	235	236	
T-32	DDAS	244	°F	245	242	237	254	257	258	258	261	259	256	257	
T-33	REC	9B-2	°F	246	242	234	251	253	256	256	259	258	255	256	
T-34	DDAS	245	°F	244	238	[illegible]	253	255	253	256	255	255	252	258	
T-35	DDAS	246	°F	245	241	250	255	257	[illegible]	257	[illegible]	252	255	256	
T-36	REC.	8B-3	°F	248	244	240	256	256	258	260	261	262	257	260	
T-37	REC.	8B-4	°F	234	229	224	242	243	244	[illegible]	247	248	244	270	
T-38	DDAS	247	°F	255	249	[illegible]	[illegible]	262	[illegible]	[illegible]	268	267	264	265	
T-39	REC.	[illegible]	°F	260	256	257	[illegible]	267	267	267	[illegible]	273	[illegible]	272	
T-40	DDAS	250	°F	239	234	229	242	250	251	253	254	250	247	248	
T-41	REC.	8A-2	°F	203	191	187	213	214	214	215	217	209	205	205	
T-42	DDAS	251	°F	213	201	196	219	221	221	223	223	221	218	216	
T-43	REC.	9B-4	°F	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
[illegible]	[illegible]	256	°F	215	270	264	281	283	284	286	286	287	286	286	
T-45	REC	8A-3	°F	232	224	220	231	236	237	238	240	244	243	243	
T-46	DDAS	257	°F	318	315	350	335	329	338	333	337	341	347	344	
T-47	DDAS	260	°F	311	285	234	300	292	278	301	303	310	311	310	

PRELIMINARY DATA

SNAP-8 DIVISION

REF: ~~TM372:63-8-149~~

Calibration Corrected and Approved
Format for Internal Distribution Only

SNAP-8
DATA REDUCTION SHEET

Prepared by	[illegible]
Checked by	[illegible]
Approved by	[illegible]

Date 6-5-64
Item GN2S-1, T-1A
Test No. D-5-R-5
W. O. No. 2741-11-4003

TIME				1815	1845	1907	1925	1927	1928	1929	1930	1934	1938	1939
FUNCTION	INSTR	POSITION	UNITS											
T-48 OPEN	DDAS	261	°F	N.A.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
F-8	REC	23A	LB/HR	2090	1820	1890	2025	2025	2030	2035	2040	2040	2000	2000
F-2	DDAS	066	LB/HR	1325	1180	1160	1280	1285	1285	1300	1300	1285	1265	1260
F-3	REC	22A	LB/HR	820	750	750	780	780	780	795	810	810	780	800
F-4	REC	9A-4	LB/HR	210	185	195	210	210	210	195	210	210	195	200
F-6	REC	9A-3	LB/HR	210	210	210	210	210	215	215	220	220	215	220
F-9	REC	9A-2	LB/HR	215	230	230	230	235	250	255	230	265	235	265
F-10	REC	9A-1	LB/HR	175	150	160	170	170	175	175	175	175	175	175
F-5	DDAS	067	LB/HR	150	130	135	150	155	155	160	160	145	140	145
F-7	DDAS	070	LB/HR	130	125	125	130	140	140	145	150	145	145	145
F-11	DDAS	071	LB/HR	110	130	115	120	125	130	125	135	135	135	130
F-12	DDAS	072	LB/HR	60	50	50	55	50	55	55	55	60	55	55
P-2	REC.	22B	PSIA	74	79	80	79	80	80	87	80	82	83	82
P-3	DDAS	117	PSIA	14.16	14.04	14.68	14.54	14.51	14.67	14.16	14.07	14.65	14.59	14.57
P-7	DDAS	130	PSIA	10.1	10.4	10.5	10.8	10.6	10.7	10.8	10.7	10.8	11.0	10.8
P-8	REC.	26A	PSIA	44.5	37.9	40.8	41.0	40.9	41.0	41.0	41.0	41.5	40.8	40.8
P-9	DDAS	131	PSIA	17.62	15.21	16.23	16.29	16.35	16.29	16.31	16.41	16.38	15.83	15.90
P-10	REC.	11A-1	PSIA	24.4	23.7	24.0	24.0	23.8	23.9	23.7	23.7	23.9	23.7	23.7
P-11	REC.	26B	PSIA	6.7	6.2	6.4	6.1	6.1	6.1	6.2	6.2	6.1	5.9	5.8
P-12	DDAS	137	PSIA	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
P-13	DDAS	140	PSIA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
P-27 PTC1	DDAS	103	PSIA	[illegible]	33.6	36.6	36.9	37.0	37.1	37.1	37.2	37.2	36.5	36.5
P-19	REC	25B	PSIA	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
P-20	DDAS	143	PSIA	2.41	2.52	2.42	2.42	2.41	2.42	2.34	2.33	2.31	2.33	2.31
P-21	REC.	24B	PSIA	86.5	88.0	96.5	95.0	95.0	95.0	95.0	95.0	94.5	95.5	95.5
P-22	DDAS	150	PSIA	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
P-23	DDAS	151	PSIA	12.4	12.3	12.4	12.3	12.4	12.4	12.3	12.4	12.3	12.4	12.4
ΔP-71	REC	7A	PSID	1.75	1.88	1.95	1.92	1.93	1.93	1.93	1.93	1.97	1.92	1.92
P-1	DDAS	107	PSIA	322.2	328.2	331.2	331.1	331.2	332.5	332.8	332.8	336.0	334.8	335.5
F-1	CALCULATED		LB/SEC	0.512	0.535	0.54	0.535	0.54	0.54	0.54	0.54	0.545	0.54	0.54
T-1	REC	25A	°F	320	341	342	343	343	343	343	343	343	343	343
T-2	REC	98-1	°F	340	360	360	360	360	360	360	360	360	360	360

Purpose See [illegible]

PRELIMINARY DATA

SNAP-8 DIVISION

REF: TM372:63-8-149

Calibration Corrected and Approved
Format for Internal Distribution Only

SNAP-8
DATA REDUCTION SHEET

Prepared by	[illegible]
Checked by	[illegible]
Approved by	[illegible]

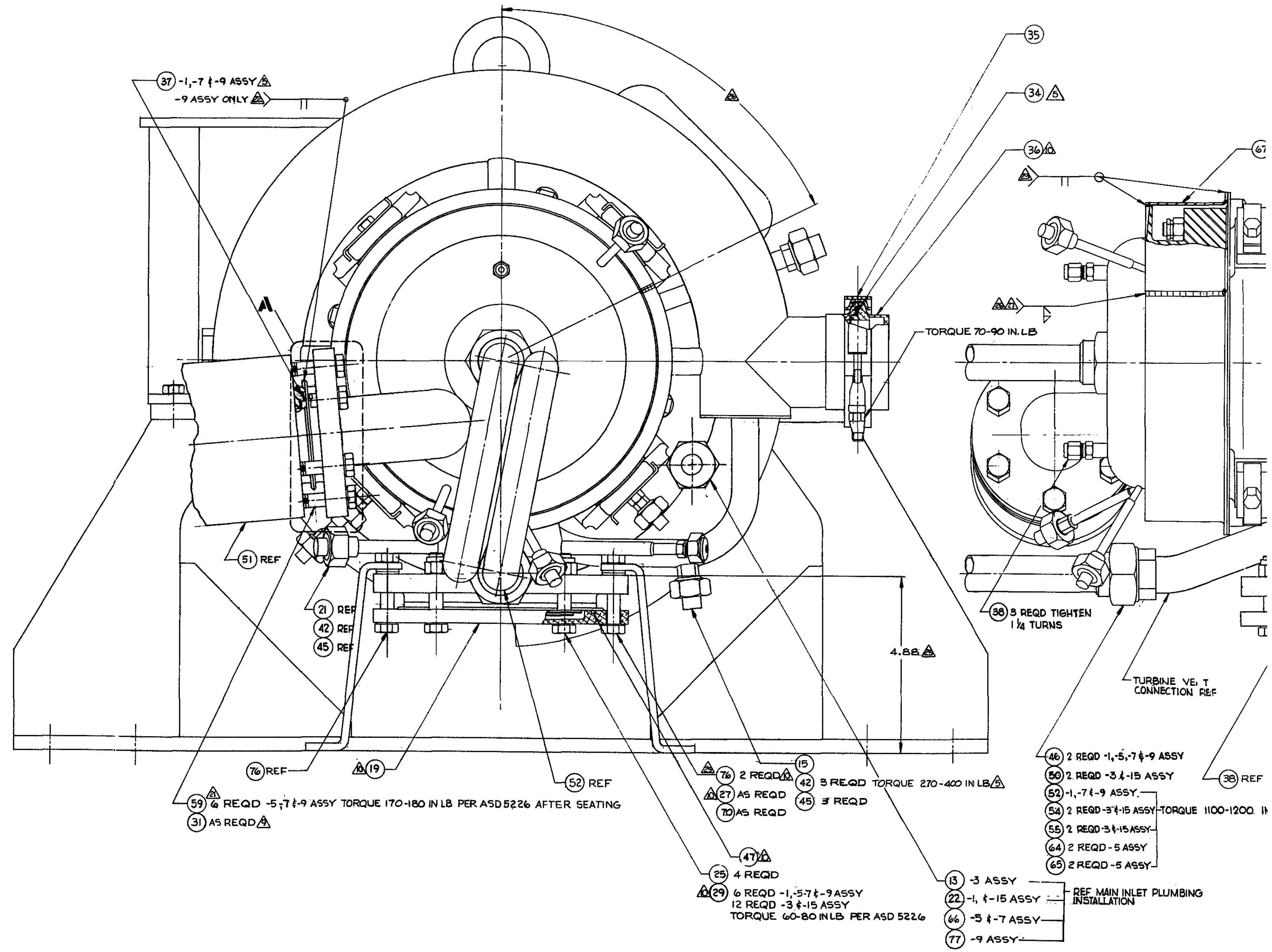
Date [illegible]
Item [illegible]
Test No. [illegible]
W. O. No. [illegible]

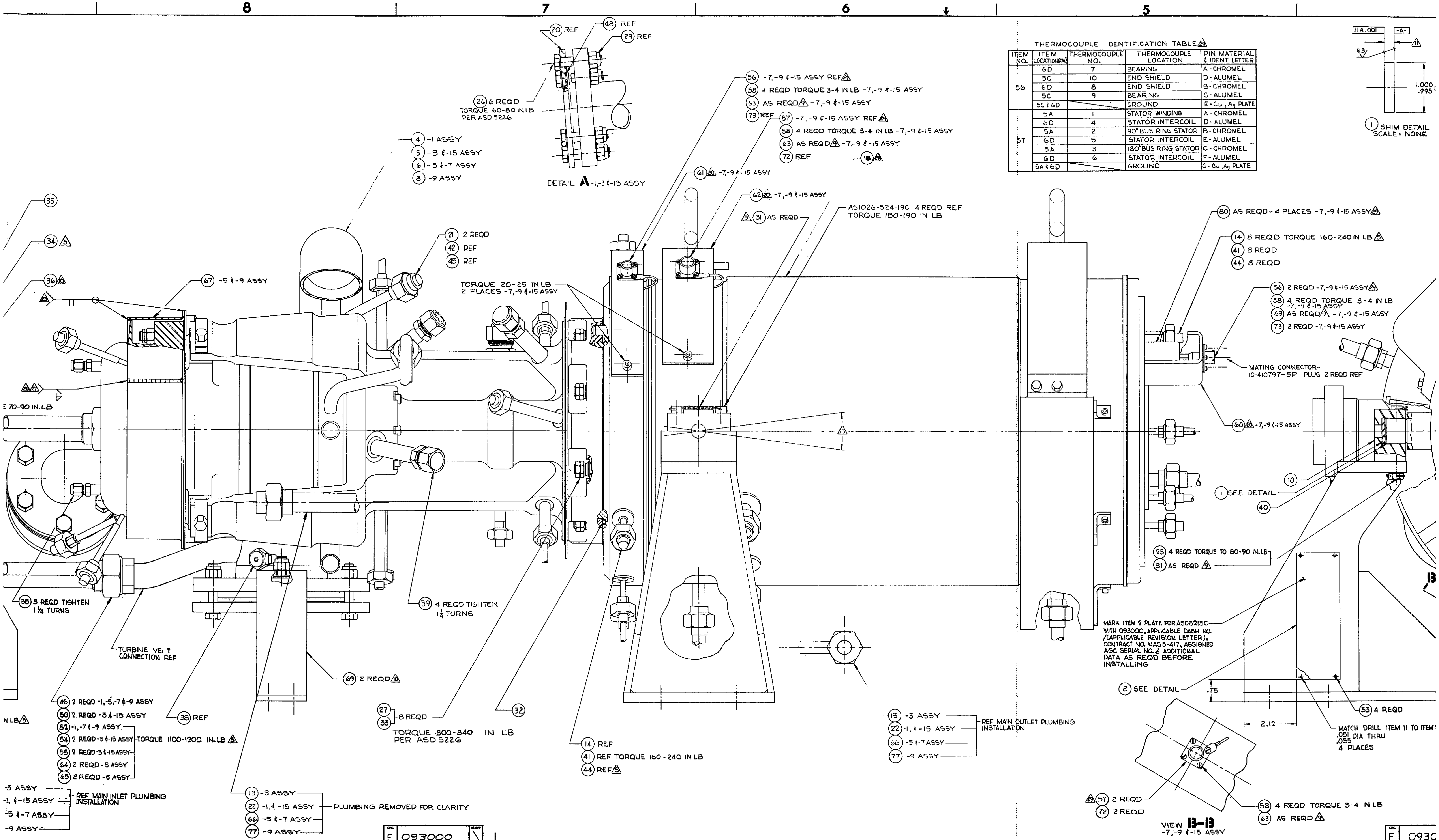
TIME				1815	1845	1907	1925	1927	1928	1929	1930	1934	1938	1939
FUNCTION	INSTR	POSITION	UNITS											
T-4	DDAS	232	°F	228	219	213	233	234	236	237	237	237	233	233
T-5	DDAS	233	°F	229	220	215	235	237	238	238	240	238	234	234
T-7	DDAS	234	°F	230	219	215	233	233	236	237	238	237	234	234
T-8	REC	9B-3	°F	175	195	195	195	195	195	195	190	195	195	195
T-9	DDAS	235	°F	184	200	199	199	198	197	196	195	195	200	200
T-10	REC	11A-2	°F	290	350	350	350	350	350	350	350	350	350	350
T-25	DDAS	HS	°F	227	221	218	234	236	237	238	239	236	233	234
T-26	DDAS	HS	°F	226	216	211	235	236	237	238	239	234	231	231
T-28	DDAS	HS	°F	259	255	250	267	269	270	271	273	272	269	270
T-29	DDAS	HS	°F	253	249	243	261	263	264	265	266	265	262	263

VI. DRAWINGS

NOTES:

1. REMOVE ALL BURRS AND SHARP EDGES.
2. INTERPRET DRAWING PER STANDARDS PRESCRIBED IN MIL-D-70327
3. WHEN MAKING OR BREAKING TUBE CONNECTIONS, DO NOT TORQUE AGAINST WELD JOINTS.
4. REMOVED.
5. ALL GASKETS MUST BE REPLACED AT EACH ASSEMBLY BUILDUP
6. HELIUM LEAK TEST USING HOOD METHOD PER MIL-STD-271. TOTAL ALLOWABLE LEAK RATE SHALL BE $1x10^{-7}$ cc/sec, ($1.3x10^{-8}$ ft^3/hr). IF TOTAL ALLOWABLE LEAK RATE IS EXCEEDED ALL LEAKS SHALL BE IDENTIFIED FOR REWORK.
7. REMOVED.
8. ASSEMBLE ALL COMPONENTS IN SNAP-8 CLEAN ROOM PER AGC-10344.
9. INSTALL LOCKWIRE PER MS33540.
10. ITEMS 17, 19, 20, 24, 25, 27, 29, 30, 36, 47, 48, 69 & 76 ARE USED FOR HANDLING, SHIPPING AND STORAGE ONLY.
11. MACHINE ITEM 1 SHIM AS REQUIRED TO OBTAIN 5 TO 25 LB PRELOAD ON ITEM NUMBER 40 SPRING.
12. EXERCISE CARE WHILE MAKING OR BREAKING ALL CONNECTIONS TO PREVENT ENTRANCE OF FOREIGN MATTER INTO INTERIOR PASSAGES.
13. TURBINE ALTERNATOR ROTATION ON PIVOT MUST NOT EXCEED 15°
14. FOR INSTRUMENTATION INSTALLATION SEE DRAWING NUMBER 094753.
15. CHILL ITEM 12 PIVOT BODY AS REQUIRED BEFORE INSTALLATION.
16. REMOVED.
17. PACKAGE PER MIL-P-116, METHOD III WHEN REQUIRED FOR SHIPPING AND STORAGE.
18. FOR GN_2 TEST INSTALLATION SEE DRAWING NUMBER 094473.
19. FOR RPL TEST INSTALLATION SEE DRAWING NUMBER 093984.
20. REMOVE EXISTING COVERS AND REPLACE WITH ITEMS 60, 61 and 62.
21. 093427-3 BOLT MAY BE USED IN PLACE OF ITEM 59 BOLT.
22. GAS TUNGSTEN ARC WELD PER AGC-10227/2 USING ITEM 75 WELD ROD. WELDER QUALIFICATION PER AGC-14067.
23. GAS TUNGSTEN ARC WELD PER AGC-10227/2 USING ITEM 74 WELD ROD. WELDER QUALIFICATION PER AGC-14067.
24. PENETRANT INSPECT SEAL WELDS PER MIL-I-6866, TYPE II, METHOD C. REWORK ALL DEFECTS.
25. SHIM ITEM 69 USING ITEM 70 AND 27 AS REQUIRED TO OBTAIN DIMENSION SHOWN.
26. ANGULAR LOCATION OF LONGITUDINAL SEAL WELD ON ITEM 67 IS OPTIONAL.
27. GAS TUNGSTEN ARC WELD PER AGC-10227 TYPE 1b USING ITEM 74 WELD ROD. WELDER QUALIFICATION PER AGC-14067.
28. VENDOR ITEM, SEE SPECIFICATION CONTROL DRAWING FOR PROCUREMENT OF ALTERNATOR.
29. SUGGESTED PROCEDURE FOR CONNECTING ALTERNATOR THERMOCOUPLE LEADS TO ITEMS 56 AND 57:
    - A. WELD THERMOCOUPLE LEADS TO APPLICABLE RECEPTACLE PINS PER AGC-10331 USING HEAT SINK-WELDING CLAMP ON RECEPTACLE PIN AND LOW WELDING CURRENT.
    - B. WELD ITEM 78 GROUND WIRE TO APPLICABLE RECEPTACLE PIN PER AGC-10331. SECURE ITEM 79 TERMINAL LUG TO ITEM 78 AND ATTACH TO ALTERNATOR AS SHOWN.
    - C. POT LEAD WIRES WITH ITEM 80 POTTING COMPOUND AND CURE PER MANUFACTURER'S INSTRUCTIONS. MANUFACTURER'S CODE IDENT. NO. 71984.
30. LENGTH OF ITEM 78 TO BE DETERMINED AT ASSEMBLY.





THERMOCOUPLE IDENTIFICATION TABLE

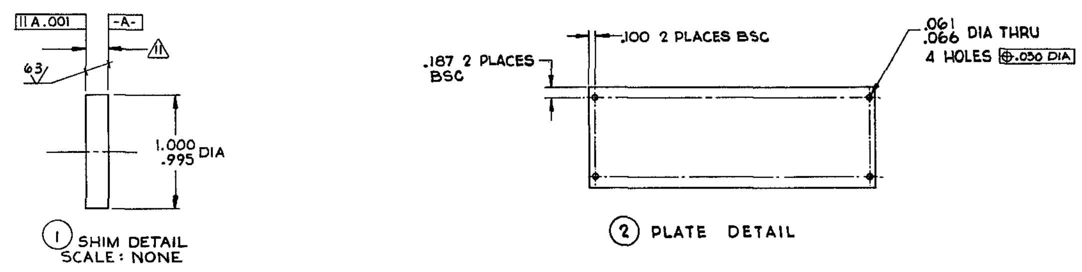
ITEM NO.	ITEM LOCATION	THERMOCOUPLE NO.	THERMOCOUPLE LOCATION	PIN MATERIAL & IDENT LETTER
56	6D	7	BEARING	A - CHROMEL
	5C	10	END SHIELD	D - ALUMEL
	6D	8	END SHIELD	B - CHROMEL
	5C	9	BEARING	C - ALUMEL
	5C & 6D		GROUND	E - Cu, Ag PLATE
57	5A	1	STATOR WINDING	A - CHROMEL
	6D	4	STATOR INTERCOIL	D - ALUMEL
	5A	2	90° BUS RING STATOR	B - CHROMEL
	6D	5	STATOR INTERCOIL	E - ALUMEL
	5A	3	180° BUS RING STATOR	C - CHROMEL
	6D	6	STATOR INTERCOIL	F - ALUMEL
	5A & 6D		GROUND	G - Cu, Ag PLATE

2

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED
D		REDRAWN WITH CHANGES REPLACES 093000 C CHANGE	10-29-64	
E		SEE INCORP ADCN	12-10-64	
F		SEE DCN	2-16-65	

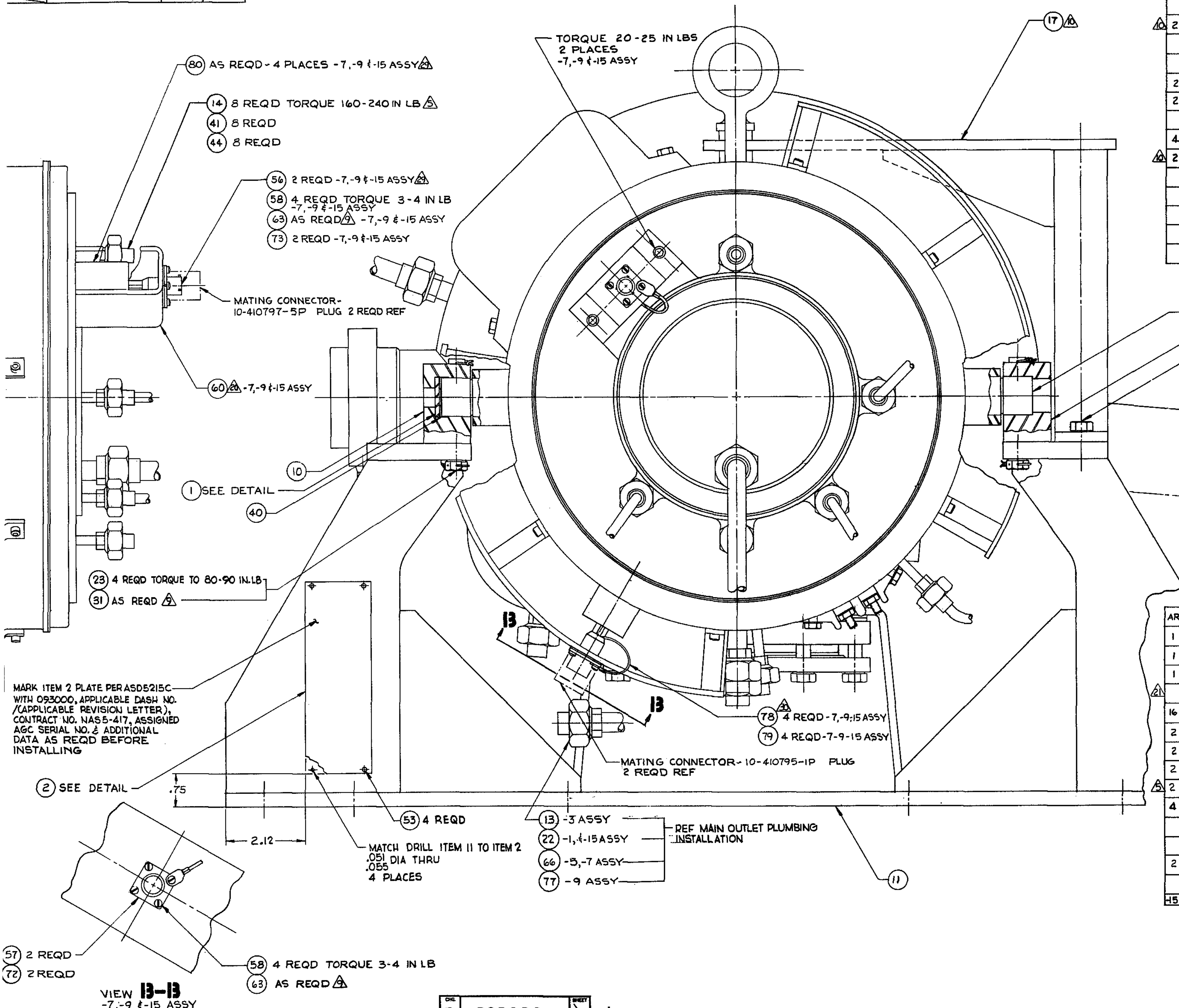
DENTIFICATION TABLE

COUPLE	THERMOCOUPLE LOCATION	PIN MATERIAL & IDENT LETTER
	BEARING	A - CHROMEL
	END SHIELD	D - ALUMEL
	END SHIELD	B - CHROMEL
	BEARING	C - ALUMEL
	GROUND	E - Cu, Ag PLATE
	STATOR WINDING	A - CHROMEL
	STATOR INTERCOIL	D - ALUMEL
	90° BUS RING STATOR	B - CHROMEL
	STATOR INTERCOIL	E - ALUMEL
	180° BUS RING STATOR	C - CHROMEL
	STATOR INTERCOIL	F - ALUMEL
	GROUND	G - Cu, Ag PLATE



(1) SHIM DETAIL
SCALE: NONE

(2) PLATE DETAIL



VIEW 13-13
-7, -9 & -15 ASSY

-15	-9	-7	-5	-3	-1	SYM	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT.	ZONE	ITEM NO.
AR	AR	AR					71984	SILICONE RUBBER #183	POTTING COMPOUND				5C	80
4	4	4					03612	YAV18-T5	LUG				3A	79
4	4	4						-21	WIRE	18 GAGE (AWG) BARE COPPER WIRE	QQ-W-343 TYPE S HARD DRAWN		3A	78
	1							094468-41	PLUMBING INSTL				8A	77
2	2	2	2	2	2			AN6C21A	BOLT				9A	76
	AR								WELD ROD	CRES 316	ASTM-A371-53T CL ER316			75
	AR		AR						WELD ROD	CRES 347	MIL-R-5031 CL 5A			74
2	2	2					93428	10-40450-14S	GASKET				5C	73
2	2	2					93428	10-40450-16S	GASKET				5A	72
								REMOVED						71
4	4	4	4	4	4			AN960C616L	WASHER				9A	70
2	2	2	2	2	2			094285-1	BRACKET				8A	69
								REMOVED						68
	1		1					092042-1	RING				8C	67
		1	1					093625-5	PLUMBING INSTL				8A	66
			2				98625	54974-16	NUT				8A	65
			2					093991-23	FLANGE				8A	64
AR	AR	AR						MS20995 C20	LOCKWIRE					63
1	1	1						095792-1	COVER				6C	62
1	1	1						096473-1	COVER				6C	61
1	1	1						096544-1	COVER				5C	60
	6	6	6					NAS1006-16H	BOLT				10A	59
16	16	16						AN500AD3-4	SCREW					58
2	2	2					93428	10-410796-1S	RECEPTACLE				5A	57
2	2	2					93428	10-410798-5S	RECEPTACLE				5C	56
2				2			98625	54974-8	NUT				9A	55
2				2			98625	54973-8S	GASKET				9A	54
4	4	4	4	4	4			AN535-00-3	SCREW, DRIVE				4A	53
	1	1			1			095538-1	TUBE				9A	52
	1	1	1					095314-1	FILTER				2B	51
2				2				093991-5	FLANGE				9A	50
								REMOVED						49
1	1	1	1	1	1		83259	2-145-77-545	O-RING				2B	48
1	1	1	1	1	1		83259	2-159-77-545	O RING				9A	47
2	2	2	2		2		98625	54973-16S	GASKET				9A	46
3	3	3	3	3	3		98625	54973-6S	GASKET				9A	45
8	8	8	8	8	8		98625	54973-4S	GASKET				5C	44
								REMOVED						43
3	3	3	3	3	3		98625	54974-6	NUT				9A	42
8	8	8	8	8	8		98625	54974-4	NUT				5C	41
1	1	1	1	1	1		05341	BS-1-7/16-1.25	SPRING				5B	40
4	4	4	4	4	4		02570	810-P-316	PLUG				7B	39
3	3	3	3	3	3		02570	200-P-316	PLUG				9B	38
	1	1	1		1		98625	50887-175-S	GASKET				10C	37
1	1	1	1	1	1		98625	55520-250-A-4	FLANGE				9C	36
1	1	1	1	1	1		98625	50773H-250-S	COUPLING				9C	35
1	1	1	1	1	1		98625	50887-250-S	GASKET				9C	34
8	8	8	8	8	8		85639	FIC624-1	NUT				8A	33
1	1	1	1	1	1			NAS1593-262	PACKING				7A	32
AR	AR	AR	AR	AR	AR			MS20995C32	LOCKWIRE				11A	31
	6	6	6		6			AN6C7A	BOLT				2B	30
12	6	6	6	12	6			MS20365-624	NUT				9A 10A	29
								REMOVED						28
14	14	14	14	14	14			AN960C616	WASHER				8A 9A	27
6				6	6			AN6C15A	BOLT				7D	26
4	4	4	4	4	4			AN6C17A	BOLT				9A	25
2	2	2	2	2	2			AN75A5	BOLT				2C	24
4	4	4	4	4	4			AN5CH6A	BOLT				2B	23
1					1			094468-1	PLUMBING INSTL				8A	22
2	2	2	2	2	2			094795-3	FLANGE				7C	21
1	1	1	1	1	1			094294-1	COVER				2B	20
1	1	1	1	1	1			094293-1	COVER				10A	19
1	1	1	1	1	1			094162	ALTERNATOR				6D	18
1	1	1	1	1	1			094138-1	BRACKET				3D	17
								REMOVED						16
1	1	1	1	1	1			093991-3	FLANGE				9A	15
8	8	8	8	8	8			093991-1	FLANGE				5C	14
				1				093625-1	PLUMBING INSTL				8A	13
2	2	2	2	2	2			093089-1	PIVOT BODY				3C	12
1	1	1	1	1	1			092592-1	MOUNT				3A	11
1	1	1	1	1	1			092583-3	HOUSING				4B	10
1	1	1	1	1	1			092583-1	HOUSING				3C	9
	1							092100-9	TURBINE				7D	8
								REMOVED						7
		1	1					092100-5	TURBINE				7D	6
1				1				092100-3	TURBINE				7D	5
					1			092100-1	TURBINE				7D	4
								REMOVED					8A	3
1	1	1	1	1	1			-13	PLATE, IDENTIFICATION	ALTER FROM 094744-1			5A	2
1	1	1	1	1	1			-11	SHIM	1.00 DIA BAR CRES CL 410 COLD FINISHED	QQ-S-763 CL 410 COND A		5B	1

QTY REQD

LIST OF MATERIALS

-5	1		FINAL	AGAN-0010
-15	1		FINAL	AGAN-0010
-9	1			AGAN-0010
-7	1			
-5	1			
-3	1			
-1	1		FINAL	AGAN-0010
DASH NO.	QTY		NEXT ASSY	USED ON

EFFECTIVE SERIAL NO. / USAGE DATA / APPLICATION / DRAWING LEVEL

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON DECIMALS .XX ± .03 .XXX ± .010 ANGULAR ± 2°
DO NOT SCALE DRAWING

DRAWN J. CLARKE 2-11-64
CHECK 4-3-64
DESIGN 3-4-64
STRESS 3-31-64
MATERIALS 3-21-64
RELIABILITY

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

TURBINE - ALTERNATOR
ASSEMBLY
-1 MODEL

CODE IDENT NO. 70143 SIZE J DWG NO. 093000

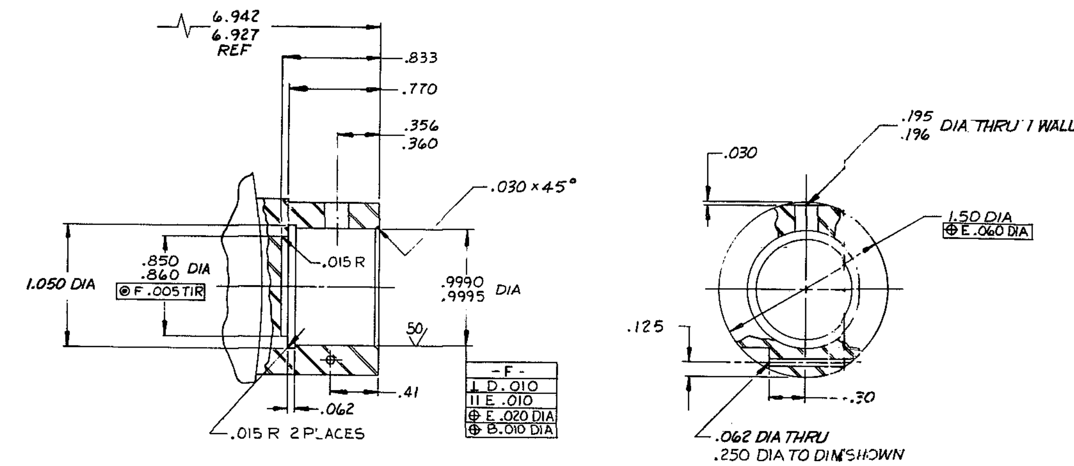
F	093000	SHEET

COPY 093000 F

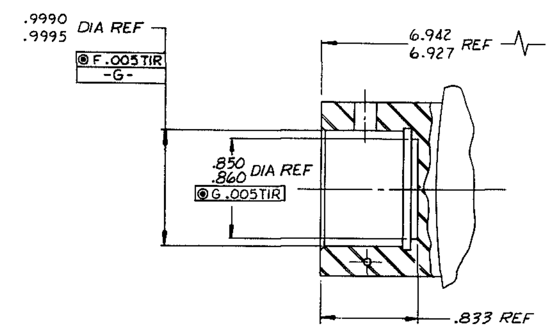
093000 F

2

NOTES:
1. REMOVE ALL BURRS AND SHARP EDGES.
2. INTERPRET DRAWING PER STANDARDS PRESCRIBED IN MIL-D-70327.
3. SPECIFICATION AGC 10175 IS APPLICABLE TO DETAIL DESIGN REQUIREMENTS.
4. EXTERIOR SURFACES TO BE PAINTED IFCO BLACK EXCEPT ON DRIVE END INSIDE DIAMETER SHOWN.
5. ALL DRILLED HEAD SCREWS TO BE SAFETY WIRED PER MS 33540.
6. DIRECTION OF ROTATION TO BE PERMANENTLY MARKED IN AN AREA CLEAR OF OBSTRUCTION AND ON NAME PLATE.
7. ALL EXPOSED THREADS, ELECTRICAL CONNECTIONS AND CRITICAL SURFACES TO BE PROTECTED AT ALL TIMES.
8. SOURCE OF SUPPLY:
PART NUMBER 2CM391A1 GENERAL ELECTRIC CO. CODE IDENTIFICATION NUMBER 80971.
9. SOURCE OF SUPPLY:
AEROQUIP CORP/MARMON DIVISION, CODE IDENTIFICATION NUMBER 98625.
10. SOURCE OF SUPPLY:
J. H. WILLIAMS & CO., CODE IDENTIFICATION NUMBER 65814.

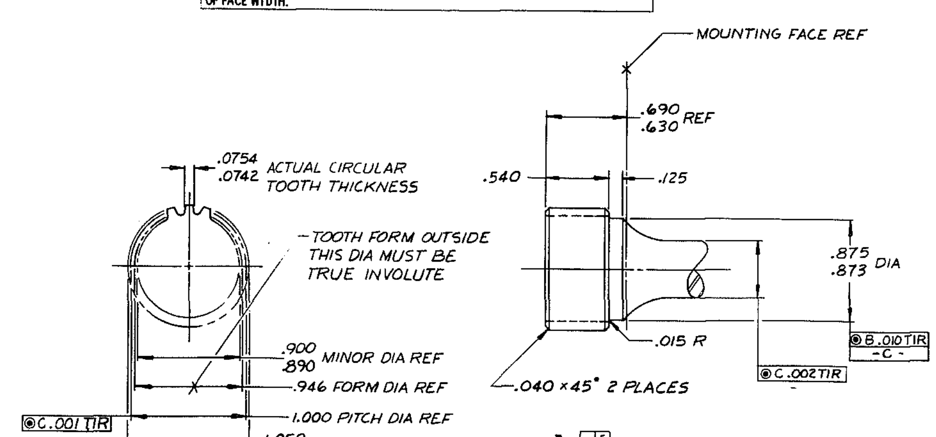


DETAIL C 2 PLACES 1 6 B
SCALE: 2/1

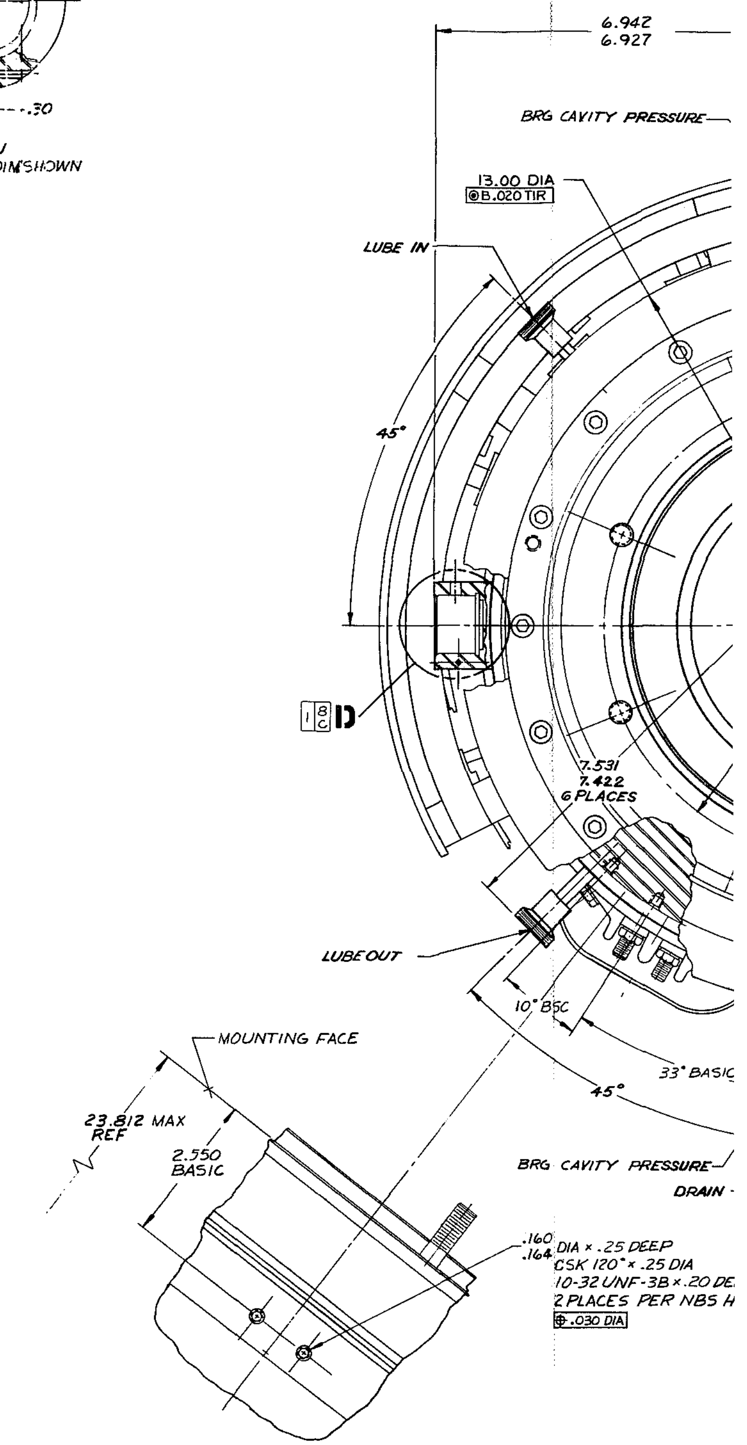


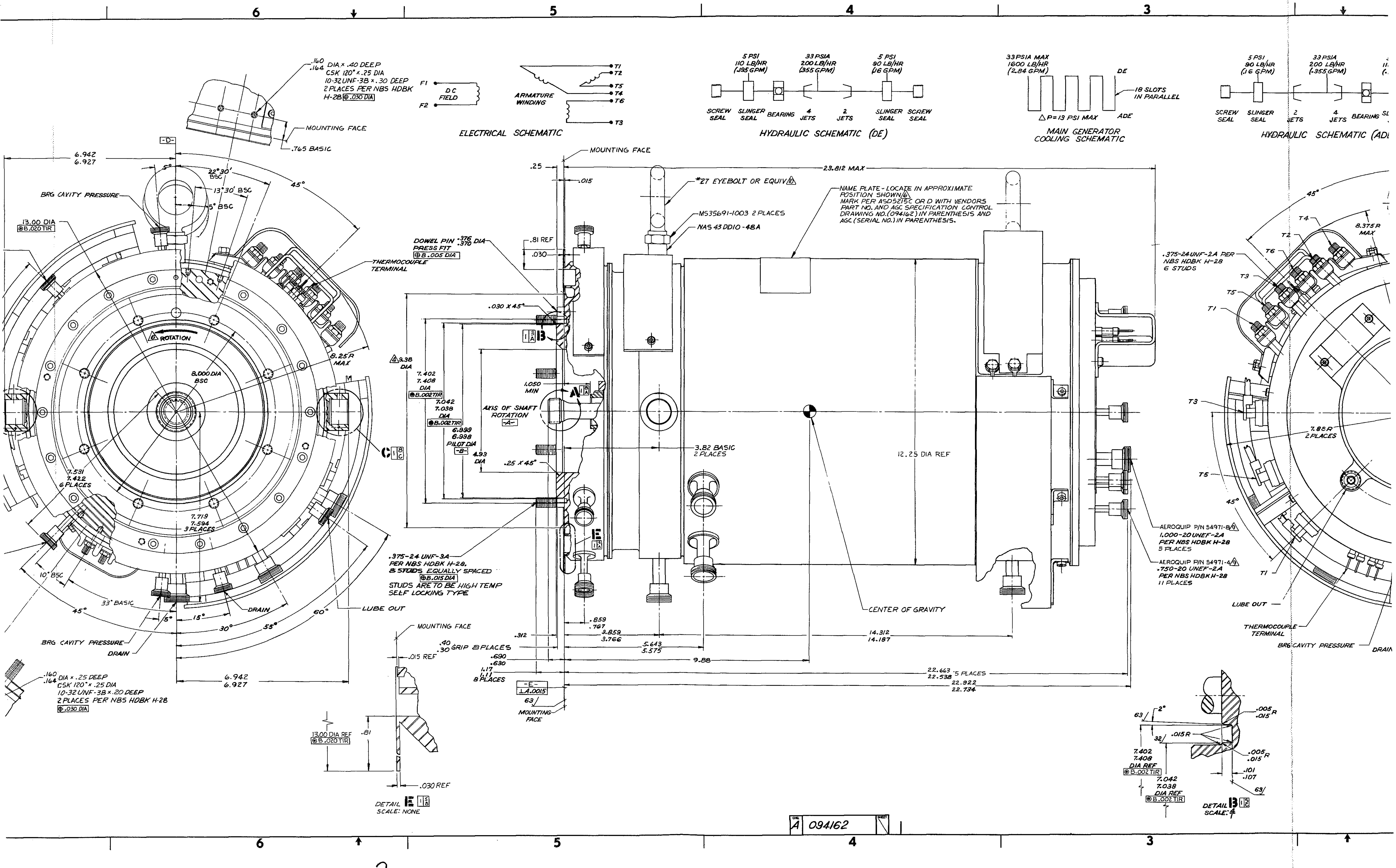
DETAIL D 1 7 C
SCALE: 2/1

INVOLUTE SPLINE DATA - FILLET ROOT SIDE FIT	
EXTERNAL (CLASS I FIT)	REF: SAE HANDBOOK 1961
NO. OF TEETH	20
DIAMETRAL PITCH	20/40
PRESSURE ANGLE	30°
PITCH DIAMETER	1.0000
PIN DIAMETER	.0960
BASE DIAMETER REF	.8660
MEASUREMENTS OVER PINS	1.1435 MAX REF 1.1417 MIN ACTUAL
FORM DIAMETER	.9460
MINOR DIAMETER	.90000/.8900
MAJOR DIAMETER	1.0500/1.0450
CIRC TOOTH THICKNESS MIN ACTUAL	.0742
CIRC TOOTH THICKNESS MAX EFFECTIVE	.0770
FINISH ON TOOTH FACE	32
ROOT FILLET RADIUS	.018 REF
RADIUS TOP LAND EDGES OF TEETH	.006/.010
CROWN SPLINE TEETH .001/.002 PER SIDE AT BOTH ENDS. SECTION THRU TOOTH AT PITCH CYLINDER AS REVEALED BY A LEAD CHECK SHOULD BE A SMOOTH CURVE APPROXIMATELY CIRCULAR IN FORM. WIRE MEASUREMENT APPLIES AT MID POINT OF FACE WIDTH.	

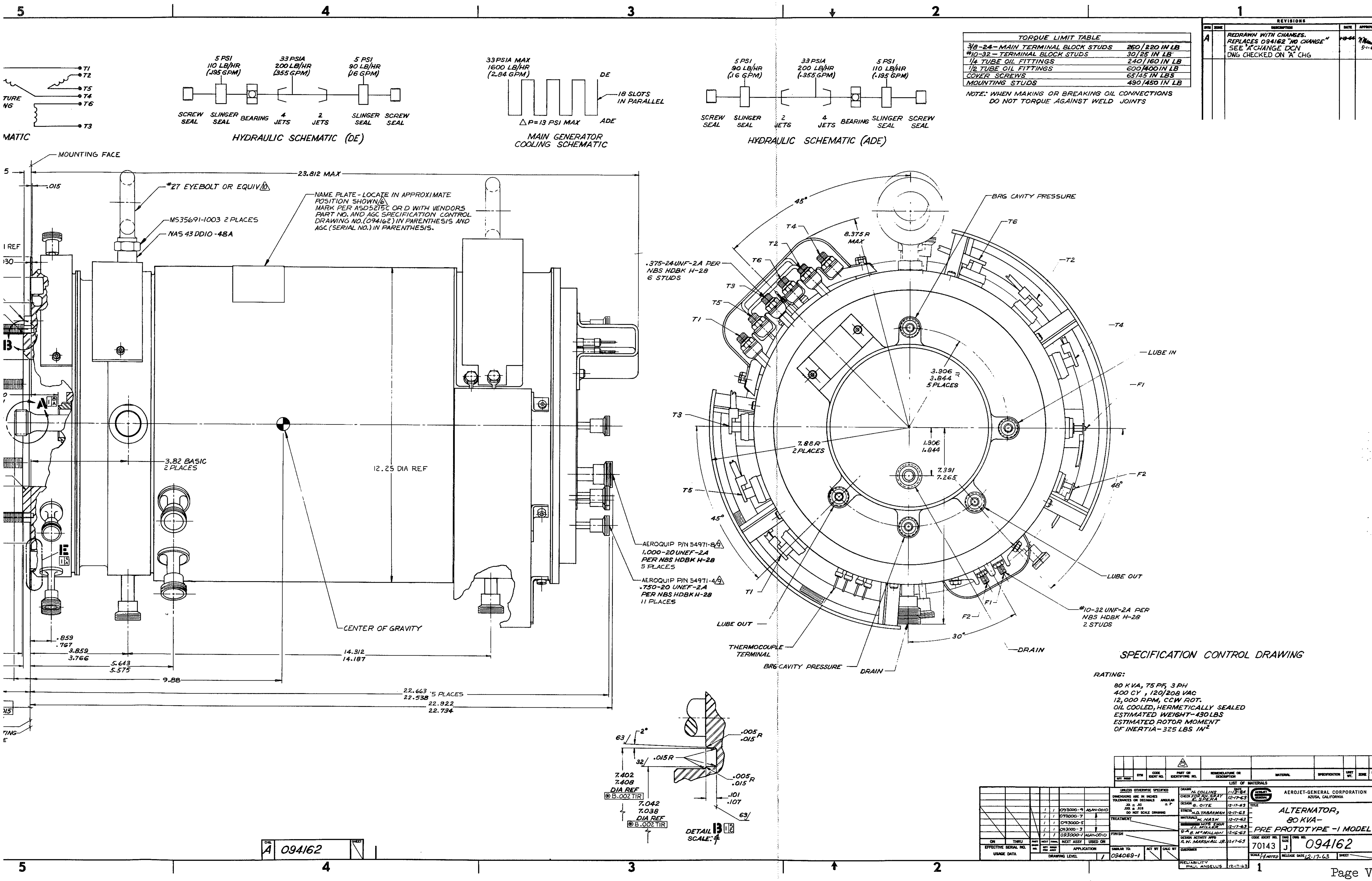


DETAIL A 1 5 B
SCALE: 2/1





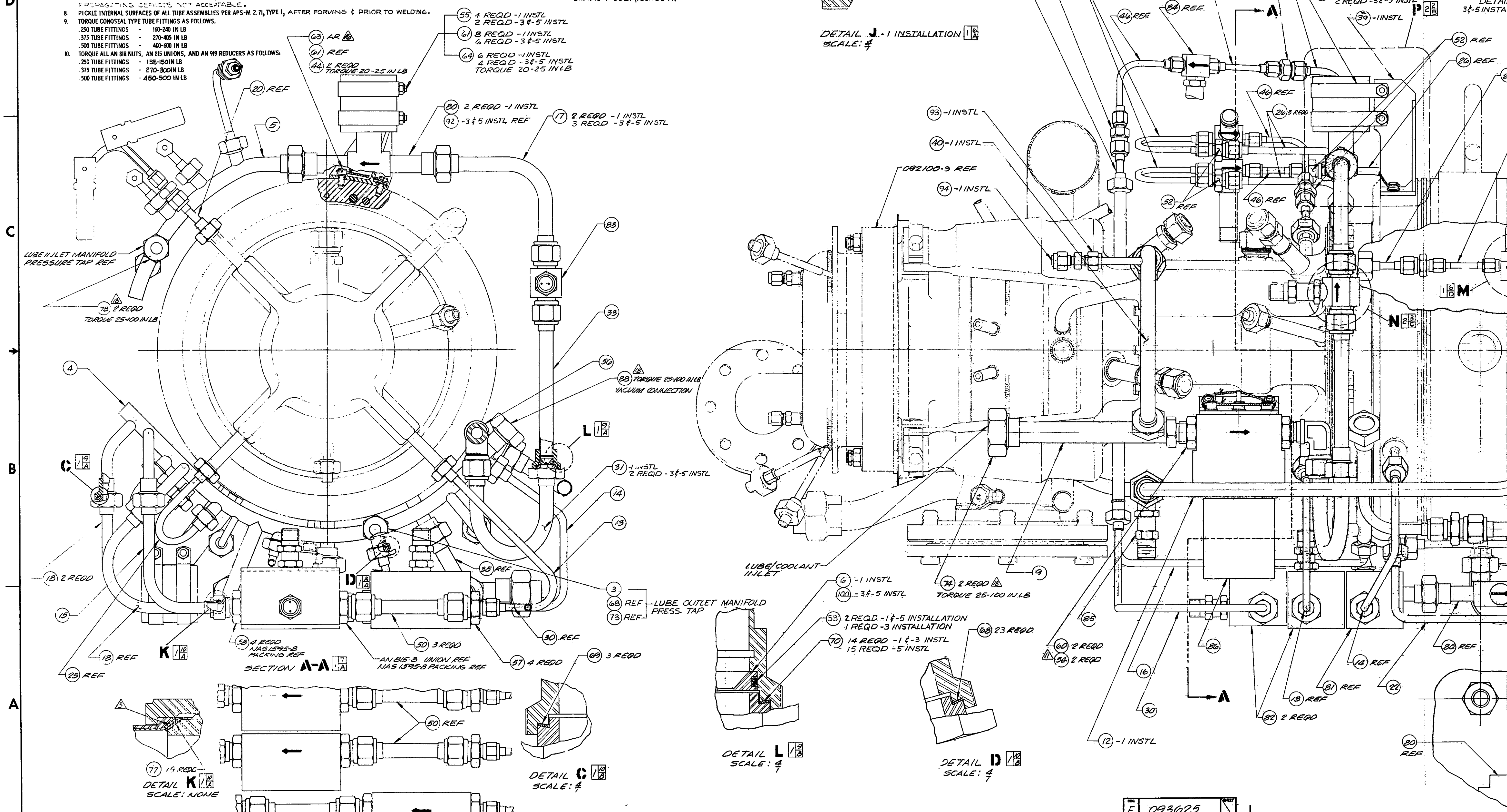
ELECTRICAL SCHEMATIC
DC FIELD
ARMATURE WINDING
HYDRAULIC SCHEMATIC (DE)
SCREW SEAL
SLINGER SEAL
BEARING
4 JETS
2 JETS
5 PSI 110 LB/HR (.195 GPM)
33 PSIA 200 LB/HR (.355 GPM)
5 PSI 90 LB/HR (.16 GPM)
MAIN GENERATOR COOLING SCHEMATIC
33 PSIA MAX 1600 LB/HR (2.84 GPM)
18 SLOTS IN PARALLEL
ΔP=13 PSI MAX
HYDRAULIC SCHEMATIC (ADE)
.160 .164 DIA x .40 DEEP CSK 120° x .25 DIA 10-32 UNF-3B x .30 DEEP 2 PLACES PER NBS HDBK H-28 .030 DIA
MOUNTING FACE
.765 BASIC
BRG CAVITY PRESSURE
13.00 DIA B.020 TIR
THERMOCOUPLE TERMINAL
ROTATION
8.000 DIA BSC
8.25 R MAX
7.531 7.422 6 PLACES
7.719 7.594 3 PLACES
33° BASIC
DRAIN
LUBE OUT
.160 .164 DIA x .25 DEEP CSK 120° x .25 DIA 10-32 UNF-3B x .20 DEEP 2 PLACES PER NBS HDBK H-28 .030 DIA
DOWEL PIN .376 .370 DIA PRESS FIT B.005 DIA
.030 x 45°
9.38 DIA
7.402 7.408 DIA B.002 TIR
7.042 7.038 DIA B.002 TIR
6.999 6.998 PILOT DIA -B-
4.93 DIA
1.050 MIN
AXIS OF SHAFT ROTATION -A-
.25 x 45°
.375-24 UNF-3A PER NBS HDBK H-28. 8 STUDS EQUALLY SPACED B.015 DIA STUDS ARE TO BE HIGH TEMP SELF LOCKING TYPE
*27 EYEBOLT OR EQUIV
MS35691-1003 2 PLACES
NAS 43 DD10-48A
NAME PLATE - LOCATE IN APPROXIMATE POSITION SHOWN. MARK PER ASD5215C OR D WITH VENDORS PART NO. AND AGC SPECIFICATION CONTROL DRAWING NO. (094162) IN PARENTHESIS AND AGC (SERIAL NO.) IN PARENTHESIS.
23.812 MAX
3.82 BASIC 2 PLACES
12.25 DIA REF
CENTER OF GRAVITY
AEROQUIP P/N 54971-8 1.000-20 UNEF-2A PER NBS HDBK H-28 5 PLACES
AEROQUIP P/N 54971-4 .750-20 UNEF-2A PER NBS HDBK H-28 11 PLACES
.40 .30 GRIP 8 PLACES
.015 REF
.030 REF
13.00 DIA REF B.020 TIR
DETAIL E SCALE: NONE
14.312 14.187
22.663 22.538 5 PLACES
22.922 22.734
9.88
5.643 5.575
3.859 3.766
.859 .767
-E- A.0015
MOUNTING FACE
.375-24 UNF-2A PER NBS HDBK H-28 6 STUDS
8.375 R MAX
7.88 R 2 PLACES
THERMOCOUPLE TERMINAL
DETAIL B SCALE: 4
A 094162


TORQUE LIMIT TABLE
3/8-24-MAIN TERMINAL BLOCK STUDS 260/220 IN LB
#10-32-TERMINAL BLOCK STUDS 30/25 IN LB
1/4 TUBE OIL FITTINGS 240/160 IN LB
1/2 TUBE OIL FITTINGS 600/400 IN LB
COVER SCREWS 65/45 IN LBS
MOUNTING STUDS 490/450 IN LB
NOTE: WHEN MAKING OR BREAKING OIL CONNECTIONS DO NOT TORQUE AGAINST WELD JOINTS
REVISIONS
A REDRAWN WITH CHANGES. REPLACES 094162 "NO CHANGE" SEE "A" CHANGE DCN DWG CHECKED ON "A" CHG
HYDRAULIC SCHEMATIC (DE)
MAIN GENERATOR COOLING SCHEMATIC
HYDRAULIC SCHEMATIC (ADE)
33 PSIA MAX 1600 LB/HR (2.84 GPM)
18 SLOTS IN PARALLEL
ΔP=13 PSI MAX
SCREW SEAL
SLINGER SEAL
BEARING
4 JETS
2 JETS
MOUNTING FACE
23.812 MAX
#27 EYEBOLT OR EQUIV
MS35691-1003 2 PLACES
NAS 43 DD10-48A
NAME PLATE - LOCATE IN APPROXIMATE POSITION SHOWN. MARK PER ASD5215C OR D WITH VENDORS PART NO. AND AGC SPECIFICATION CONTROL DRAWING NO. (094162) IN PARENTHESIS AND AGC (SERIAL NO.) IN PARENTHESIS.
12.25 DIA REF
3.82 BASIC 2 PLACES
CENTER OF GRAVITY
AEROQUIP P/N 54971-8 1.000-20 UNEF-2A PER NBS HDBK H-28 5 PLACES
AEROQUIP P/N 54971-4 .750-20 UNEF-2A PER NBS HDBK H-28 11 PLACES
.375-24 UNF-2A PER NBS HDBK H-28 6 STUDS
#10-32 UNF-2A PER NBS HDBK H-28 2 STUDS
BRG CAVITY PRESSURE
LUBE IN
LUBE OUT
DRAIN
THERMOCOUPLE TERMINAL
DETAIL B SCALE: 4/1
SPECIFICATION CONTROL DRAWING
RATING:
80 KVA, 75 PF, 3 PH
400 CY, 120/208 VAC
12,000 RPM, CCW ROT.
OIL COOLED, HERMETICALLY SEALED
ESTIMATED WEIGHT-430 LBS
ESTIMATED ROTOR MOMENT OF INERTIA-325 LBS IN²
AEROJET-GENERAL CORPORATION AZUSA, CALIFORNIA
ALTERNATOR, 80 KVA- PRE PROTOTYPE -1 MODEL
70143 J 094162
RELEASE DATE 12-17-63
RELIABILITY PAUL ANGELUS
A 094162

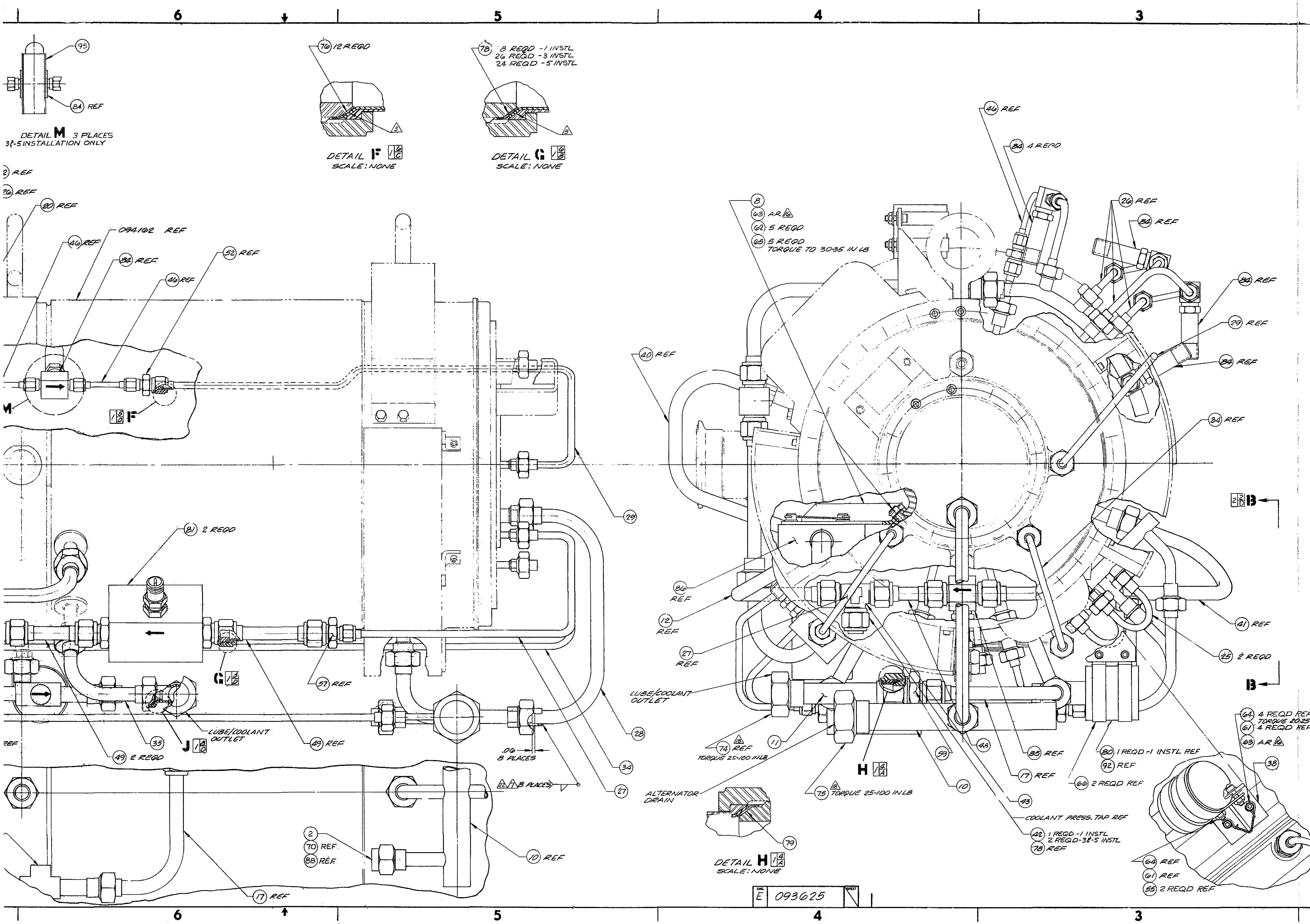
3

Page VI-3

NOTES:
1. REMOVE ALL BURRS AND SHARP EDGES.
2. INTERPRET DRAWING PER STANDARDS PRESCRIBED IN MIL-D-70327
3. MACHINED SURFACES TO BE 125/.
4. TUBE ASSEMBLIES TO BE FORMED AND TRIMMED TO SUIT INSTALLATION REQUIREMENTS ON 093080-3 TURBINE-ALTERNATOR. BEND TUBING PER MS 33611.
5. FLARE TUBE END PER MS 33584.
6. REMOVED
7. PENETRANT INSPECT WELDS PER MIL-I-6866, TYPE II, METHOD C. PROPAGATING DEFECTS NOT ACCEPTABLE.
8. PICKLE INTERNAL SURFACES OF ALL TUBE ASSEMBLIES PER APS-M 2.71, TYPE I, AFTER FORMING & PRIOR TO WELDING.
9. TORQUE CONOSEAL TYPE TUBE FITTINGS AS FOLLOWS.
   .250 TUBE FITTINGS - 160-240 IN LB
   .375 TUBE FITTINGS - 270-405 IN LB
   .500 TUBE FITTINGS - 400-600 IN LB
10. TORQUE ALL AN 818 NUTS, AN 815 UNIONS, AND AN 919 REDUCERS AS FOLLOWS:
   .250 TUBE FITTINGS - 135-150 IN LB
   .375 TUBE FITTINGS - 270-300 IN LB
   .500 TUBE FITTINGS - 450-500 IN LB
11. INSTALL FITTINGS PER AND-10064.
12. WHEN MAKING OR BREAKING TUBE CONNECTIONS, DO NOT TORQUE AGAINST WELD JOINTS.
13. ALL TUBE CONNECTOR SEALS AND GASKETS MUST BE REPLACED AT EACH ASSEMBLY BUILD UP.
14. ALL FLOW METERS, VALVES, AND FILTER MUST BE INSTALLED IN DIRECTION OF FLOW INDICATED.
15. METAL TAG PER ASD 5215M WITH ASSY 093625 APPLICABLE DASH NO./(APPLICABLE REVISION LETTER) AND ASSIGNED AGC SERIAL NO.
16. INSTALL ITEM 63 PER MS 33540.
17. AFTER PICKLING PER NOTE 8, REIDENTIFY TUBE ASSEMBLIES PER ASD 5215C.
18. SEAL INTERFACE MANIFOLD CONNECTIONS AS REQUIRED FOR SUBSEQUENT LEAK TEST (SEE DRAWING 093000) AND FOR EXCLUSIONS OF FOREIGN MATTER.
19. LUBRICATE ALL TUBE CONNECTOR THREADS SPARINGLY WITH ITEM 89 LUBRICANT.
20. TUBE CONNECTOR MAX TORQUE VALUES MAY BE EXCEEDED BY 10% IF NECESSARY FOR SUBSEQUENT LEAK TEST REQUIREMENTS ON NEXT ASSY (SEE DWG 093000).
21. THE FLOWCON CO., 1014 E. SOUTH ST., ANAHEIM, CALIFORNIA.
22. GAS TUNGSTEN ARC WELD PER AGC 10227, TYPE 16, USING ITEM 87 WELD ROD. WELDER QUALIFICATION PER MIL-T-5021, CLASS A.



E 093625



	-5	-3	-1	SYM	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION
	1	1				095946-1	BRACKET
	1					094527-3	ORIFICE
	1	1				094376-3	ORIFICE
	4	4				MS24675-7	SCREW
	1	1		21		500FT-9SR -H.M.R.-22	SHIELD
	3	3		21		500FT-9SR -H.M.R.-21	SHIELD
			1			400-P-316	PLUG
			1			400-6-316	UNION
	2	2			96487	V-54600 -05	VALVE
		1			15275	PBV-308 -PS6	VALVE
	1	1				AN827-8S	CROSS
19	AR	AR	AR		71984	MIX 4P3E	LUBRICANT
	2	2	2		98625	54974-8	NUT
	AR	AR	AR				ROD, WELDING
	1	1	1		12193	FR2-05-888	FILTER
	1	1	1		11518	R½-3J	METER
	4	4	4		11518	R3/16-3J	
	1	1	1		83475	¼-1422	
	2	2	2		83475	MF-100-4141	
	2	2	2		83475	MF-90-4141	METER
			2		96487	V-44600-15	VALVE
	1	1	1		01673	AP50C-12	SEAL
	24	26	18			-8	
	19	19	19			-6	
	12	12	12		01673	AP50C-4	SEAL
	1	1	1		98625	54974-16	NUT
	2	2	2			54974-12	NUT
	2	2	2			54974-4	NUT
	15	14	14			54973-8S	GASKET
	3	3	3			54973-6S	GASKET
	23	23	23		98625	54973-4S	GASKET
	2	2	4			MS122927	CLAMP
	5	5	5			MS24674-22	SCREW
	4	4	6			MS24673-3	SCREW
16	AR	AR	AR			MS20995-C32	LOCKWIRE
	5	5	5			AN960-C416L	WASHER
	6	6	8			AN960-C10L	WASHER
	2	2	2			AN924-8C	NUT
	1	1	1			AN919-19C	REDUCER
	4	4	4			AN919-12C	REDUCER
	4	4	4			AN919-10C	REDUCER
	1	1	1			AN833-8C	ELBOW
	2	2	4			MS20364-1032C	NUT
	2	2	2			NAS1595-8	PACKING
	2	1	2			NAS1593-013	PACKING
	8	8	8			AN919-6S	REDUCER
5		1				AS1618-48A40	TUBING ASSY
5	3	3	3			AS1618-48A14	TUBING ASSY
5	2	2	2			AS1618-48A12	TUBING ASSY
5	1	1	1			AS1618-48A8	TUBING ASSY

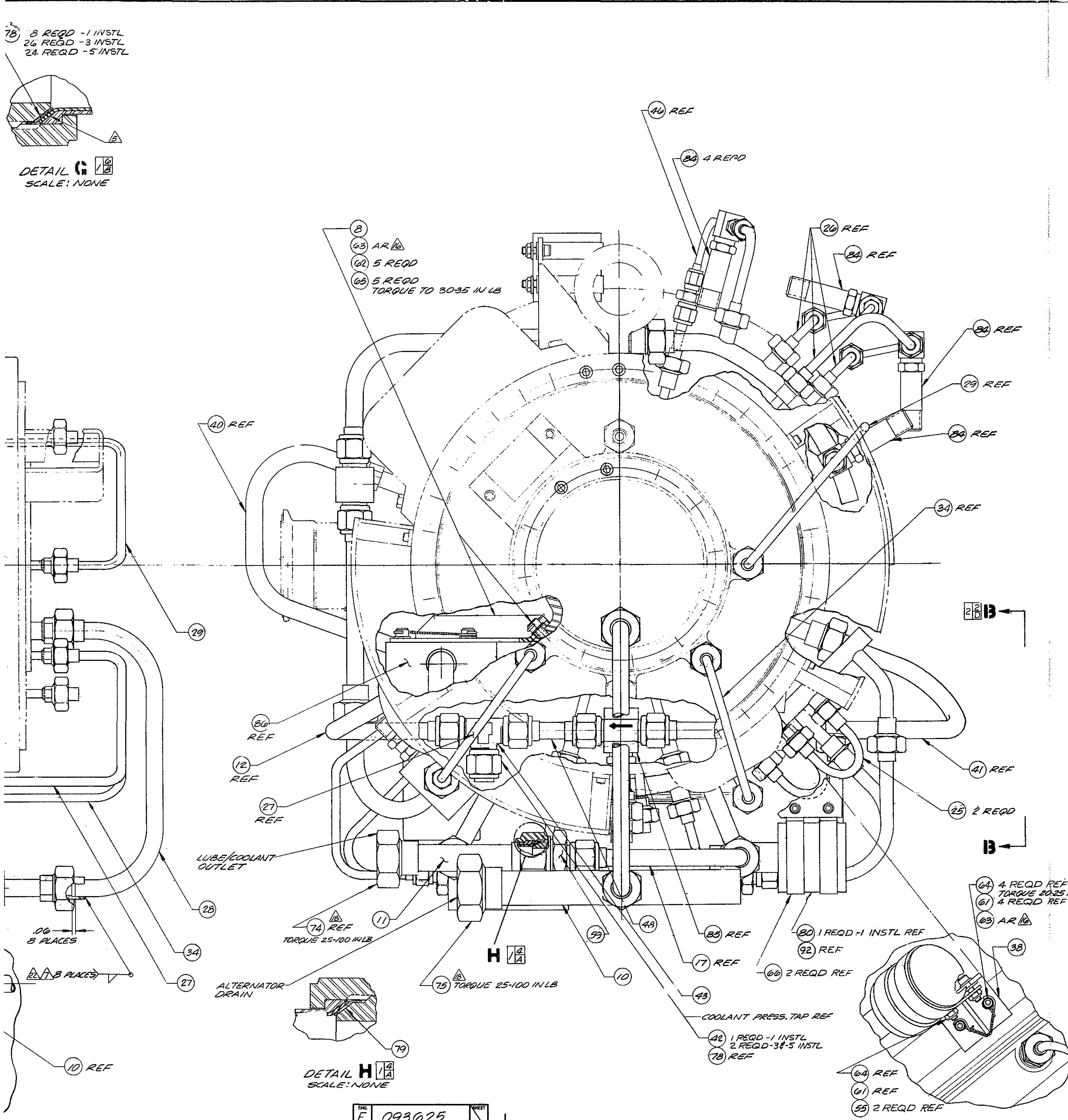
QTY REQD

LIST OF MATERIAL

E 093625

SHEET

2



	-5	-3	-1	SYM	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT.	ZONE	ITEM NO.
	1	1				095946-1	BRACKET			2	2A	102
	1					094527-3	ORIFICE			2	6A	101
	1	1				094376-3	ORIFICE			1	8A	100
	4	4				MS24675-7	SCREW			2	3B	99
												98
												97
	1	1		Δ21		500FT-9SR -H.M.R.-22	SHIELD			2	3C	96
	3	3		Δ21		500FT-9SR -H.M.R.-21	SHIELD			1	6D	95
			1			400-P-316	PLUG			1	8C	94
			1			400-6-316	UNION			1	8C	93
	2	2			96487	V-54600 -05	VALVE			2	2B	92
		1			15275	PBV-308 -PS6	VALVE			2	7B	91
	1	1				AN827-8S	CROSS			2	7C	90
Δ19	AR	AR	AR		71984	MIX 4P3E	LUBRICANT					89
	2	2	2		98625	54974-8	NUT			1	9B	88
	AR	AR	AR				ROD, WELDING	CRES 347	MIL-R5031 CLASS 5A		—	87
	1	1	1		12193	FR2-05-888	FILTER			1	7A	86
	1	1	1		11518	R½-3J	METER			1	8A	85
	4	4	4		11518	R3/16-3J				1	3D	84
	1	1	1		83475	1/4-1422				1	9C	83
	2	2	2		83475	MF-100-4141				1	7A	82
	2	2	2		83475	MF-90-4141	METER			1	6B	81
			2		96487	V-44600-15	VALVE			1	9C	80
	1	1	1		01673	AP50C-12	SEAL			1	4A	79
	24	26	18			-8				1	5D	78
	19	19	19			-6				1	10A	77
	12	12	12		01673	AP50C-4	SEAL			1	5D	76
	1	1	1		98625	54974-16	NUT			1	4A	75
	2	2	2			54974-12	NUT			1	8A	74
	2	2	2			54974-4	NUT			1	10C	73
											—	72
											—	71
	15	14	14			54973-85	GASKET			1	8A	70
	3	3	3			54973-65	GASKET			1	9A	69
	23	23	23		98625	54973-45	GASKET			1	8A	68
											—	67
	2	2	4			MS122927	CLAMP			1	7D	66
	5	5	5			MS24674-22	SCREW			1	4D	65
	4	4	6			MS24673-3	SCREW			1	9D	64
Δ16	AR	AR	AR			MS20995-C32	LOCKWIRE				—	63
	5	5	5			AN960-C416L	WASHER			1	4D	62
	6	6	8			AN960-C10L	WASHER			1	9D	61
	2	2	2			AN924-8C	NUT			1	8A	60
	1	1	1			AN919-19C	REDUCER			1	3A	59
	4	4	4			AN919-12C	REDUCER			1	10A	58
	4	4	4			AN919-10C	REDUCER			1	9A	57
	1	1	1			AN833-8C	ELBOW			1	9B	56
	2	2	4			MS20364-1032C	NUT			1	9D	55
	2	2	2			NAS1595-8	PACKING			1	8A	54
	2	1	2			NAS1593-013	PACKING			1	8A	53
	8	8	8			AN919-6S	REDUCER			1	7D	52
Δ5		1				AS1618-48A40	TUBING ASSY			2	5B	51
Δ5	3	3	3			AS1618-48A14	TUBING ASSY			1	9A	50
Δ5	2	2	2			AS1618-48A12	TUBING ASSY			1	6A	49
Δ5	1	1	1			AS1618-48A8	TUBING ASSY			1	4A	48

	-5	-3	-1	SYM	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT.	ZONE	ITEM NO.
Δ5	1	2				AS1618-48A75	TUBING ASSY			2	5D	47
Δ5	6	6	6			AS1618-34C20	TUBING ASSY			1	8D	46
Δ5	2	2	2			AS1618-34C40	TUBING ASSY			1	7D	45
	2	2	2			MS24673-1	SCREW			1	10D	44
	1	1	1			AN824-8C	TEE			1	3A	43
	2	2	1			AN929-8C	CAP ASSY			1	3A	42
Δ5	1	1	1			094686-5	TUBE ASSY			2	2D	41
Δ22 Δ7			1			094686-3	TUBE ASSY			1	8C	40
			1			094668-1	BRACKET			1	7D	39
	1	1	1			094647-1	BRACKET			1	3A	38
			1			094527-1	ORIFICE			1	8D	37
											—	36
Δ22 Δ7	1	1	1			094479-51	TUBE ASSY			1	6A	35
Δ22 Δ7	1	1	1			-49				1	5A	34
Δ5	1	1	1			-47				1	9C	33
Δ5	1					53				2	5A	32
Δ5	2	2	1			-43				1	9B	31
Δ5	1	1	1			-37				1	7A	30
Δ5	1	1	1			-35				1	5B	29
Δ22 Δ7	1	1	1			-33				1	5A	28
Δ5	1	1	1			-31				1	5A	27
Δ5	3	3	3			-29				1	7D	26
Δ22 Δ7	2	2	2			-27				1	3B	25
Δ5	1					094479-45				2	4A	24
						REMOVED						23
Δ22 Δ7	1	1	1			094479-21				1	7A	22
											—	21
Δ5	4	4	4			-17				1	7D	20
											—	19
Δ5	2	2	2			-13				1	10B	18
Δ5	3	3	2			-11				1	9C	17
Δ22 Δ7	1	1	1			-9				1	8A	16
Δ5	1	1	1			-7				1	10A	15
Δ5	1	1	1			-5				1	9B	14
Δ5	1	1	1			-3				1	9B	13
Δ5			1			094479-1	TUBE ASSY			1	8A	12
	1	1	1			094456-1	MANIFOLD			1	4A	11
	1	1	1			094422-1	MANIFOLD			1	4A	10
	1	1	1			094414-1	MANIFOLD			1	8B	9
	1	1	1			094383-1	BRACKET			1	4C	8
	1	1				094912-1	TEE			2	4D	7
			1			094376-1	ORIFICE			1	8A	6
	1	1	1			094374-3	MANIFOLD			1	10C	5
	1	1	1			094373-1	MANIFOLD			1	10B	4
	1	1	1			093991-1	FLANGE			1	9A	3
	1	1	1			093991-5	FLANGE			1	5A	2
											—	1

LIST OF MATERIALS

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED
E		REDRAWN WITH CHANGES REPLACES 093625 "B" REVISON. INCORPORATED C&D ADCN	10-13-64	R.Y. Vial 10-14-64

PART NO.	NEXT ASSY	USED ON
-5	093000-5	AGAN-0010
-3	093000-5	
-1	093000-5	
-1	093000-11	
-1	093000-3	AGAN-0010

EFFECTIVE SERIAL NO. ON THRU — USAGE DATA — APPLICATION — DRAWING LEVEL 1

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON DECIMALS .XX ± .03 .XXX ± .010 ANGULAR ± 2°
DO NOT SCALE DRAWING
TREATMENT
FINISH

		DATE
DRAWN	A. CONTRERAS	2-28-64
CHECK	W. Mamuyama	4-2-64
DESIGN	J. W. Callahan	3-26-64
STRESS	H. F. Hofan	3-27-64
MATERIALS		3-27-64
Q.A.		3-27-64
DESIGN ACTIVITY APP.		3-8-64
CUSTOMER RELIABILITY	PAUL ANGE	3-27-64

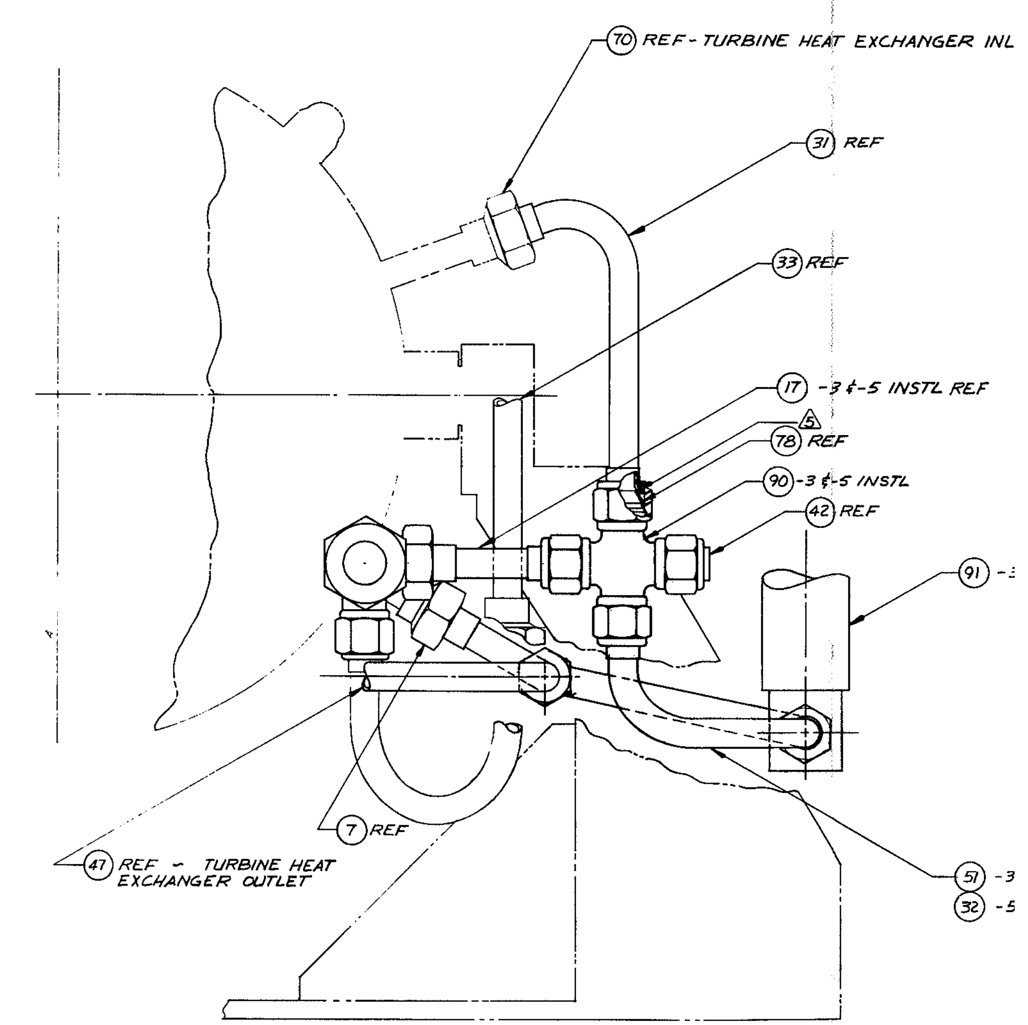
AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

TITLE: PLUMBING INSTALLATION, TAA LUBE/COOLANT -1 MODEL

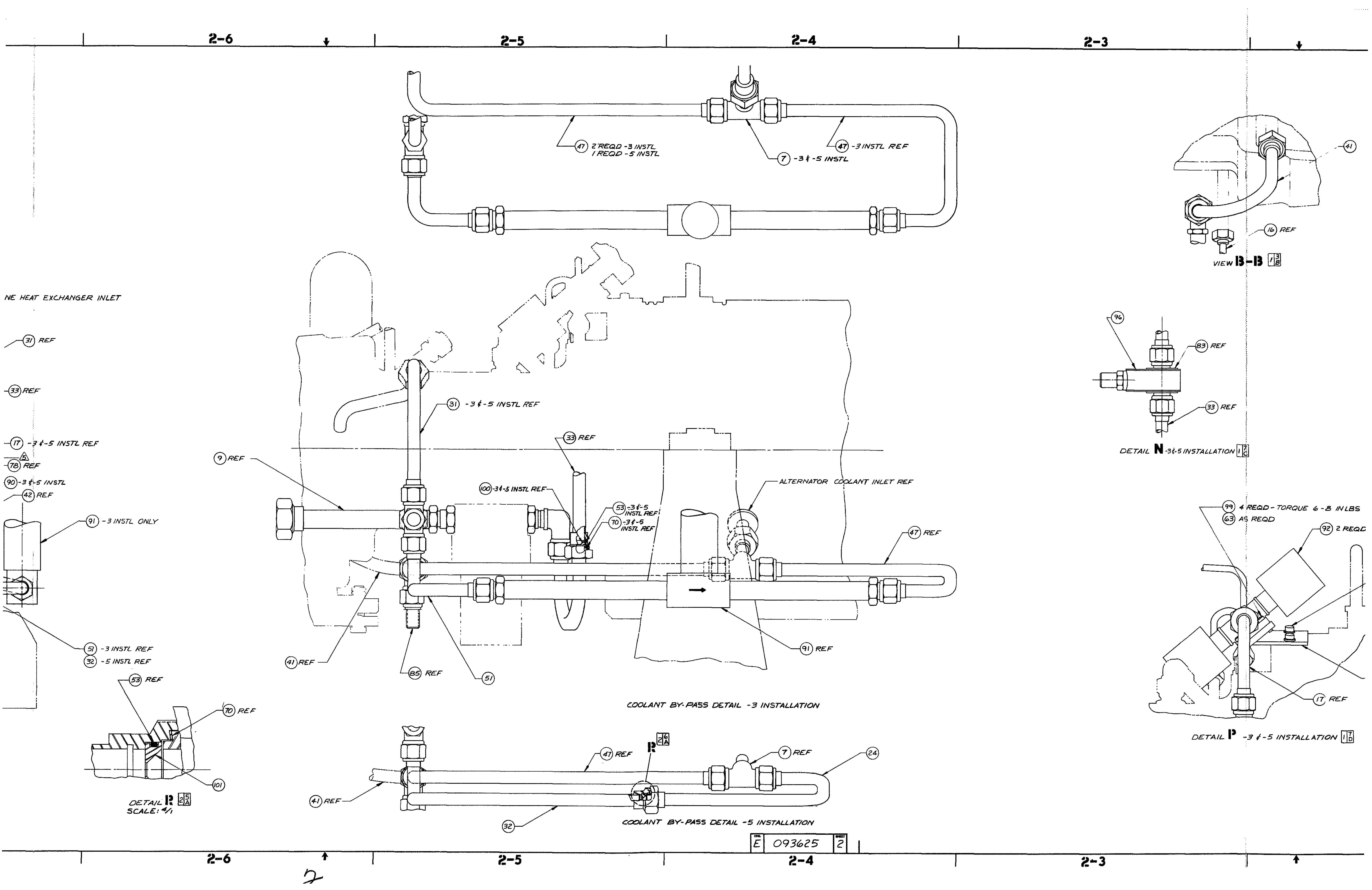
CODE IDENT NO. 70143 — DWG SIZE J — DWG NO. 093625
RELEASE DATE 4-8-64 — SHEET 1 OF 2

3

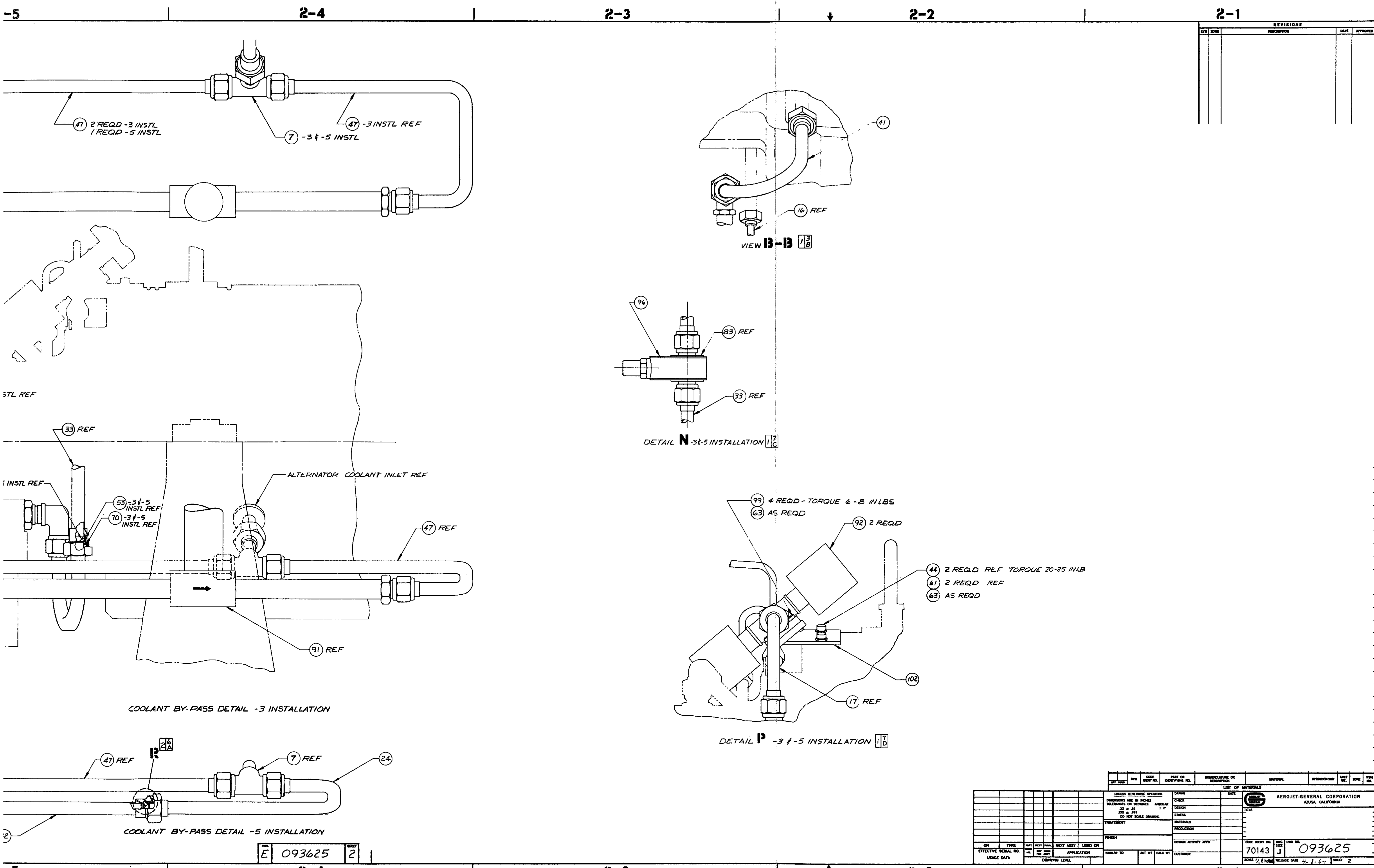
NOTES:



DWG		SHEET
E	093625	2



2-6
2-5
2-4
2-3
47 2 REQD -3 INSTL 1 REQD -5 INSTL
7 -3 & -5 INSTL
47 -3 INSTL REF
41
16 REF
VIEW B-B
NE HEAT EXCHANGER INLET
31 REF
33 REF
17 -3 & -5 INSTL REF
78 REF
90 -3 & -5 INSTL
42 REF
91 -3 INSTL ONLY
51 -3 INSTL REF
32 -5 INSTL REF
31 -3 & -5 INSTL REF
9 REF
33 REF
100 -3 & -5 INSTL REF
53 -3 & -5 INSTL REF
70 -3 & -5 INSTL REF
ALTERNATOR COOLANT INLET REF
47 REF
91 REF
41 REF
85 REF
51
96
83 REF
33 REF
DETAIL N -3 & -5 INSTALLATION
99 4 REQD - TORQUE 6-8 IN LBS
63 AS REQD
92 2 REQD
17 REF
DETAIL P -3 & -5 INSTALLATION
COOLANT BY-PASS DETAIL -3 INSTALLATION
53 REF
70 REF
101
DETAIL R
SCALE: 4/1
47 REF
R
7 REF
24
41 REF
32
COOLANT BY-PASS DETAIL -5 INSTALLATION
E 093625 2



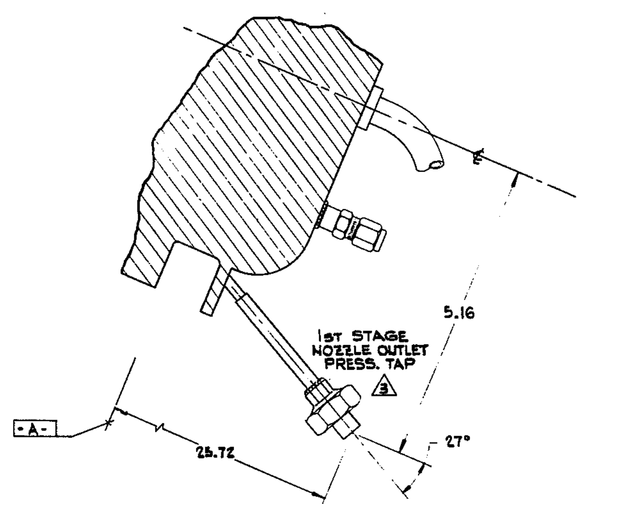
2-5
2-4
2-3
2-2
2-1
REVISIONS
SYM ZONE DESCRIPTION DATE APPROVED
D
C
B
A
COPY 093625 E
093625 E
47 2 REQD -3 INSTL
1 REQD -5 INSTL
7 -3 & -5 INSTL
47 -3 INSTL REF
41
16 REF
VIEW B-B 1/3B
96
83 REF
33 REF
DETAIL N -3&-5 INSTALLATION 1/7C
STL REF
33 REF
INSTL REF
53 -3&-5 INSTL REF
70 -3&-5 INSTL REF
ALTERNATOR COOLANT INLET REF
47 REF
91 REF
COOLANT BY-PASS DETAIL -3 INSTALLATION
99 4 REQD - TORQUE 6-8 IN LBS
63 AS REQD
92 2 REQD
44 2 REQD REF TORQUE 20-25 IN LB
61 2 REQD REF
63 AS REQD
102
17 REF
DETAIL P -3 & -5 INSTALLATION 1/7D
47 REF
R 2/6A
7 REF
24
2
COOLANT BY-PASS DETAIL -5 INSTALLATION
CHG E 093625 SHEET 2
LIST OF MATERIALS
AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA
CODE IDENT NO. 70143
SIZE J
DWG NO. 093625
RELEASE DATE 4-3-64
SHEET 2

.3

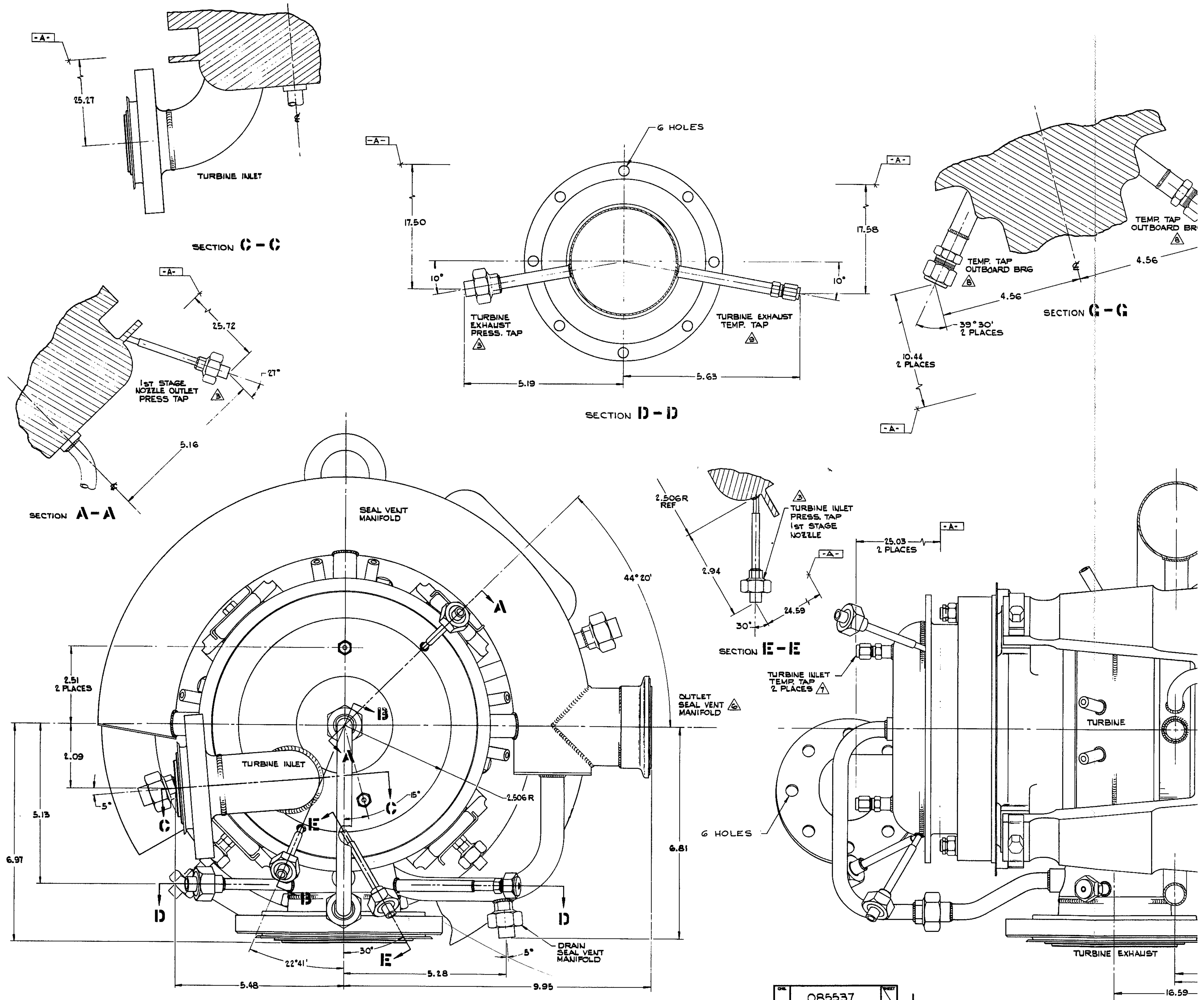
NOTES:

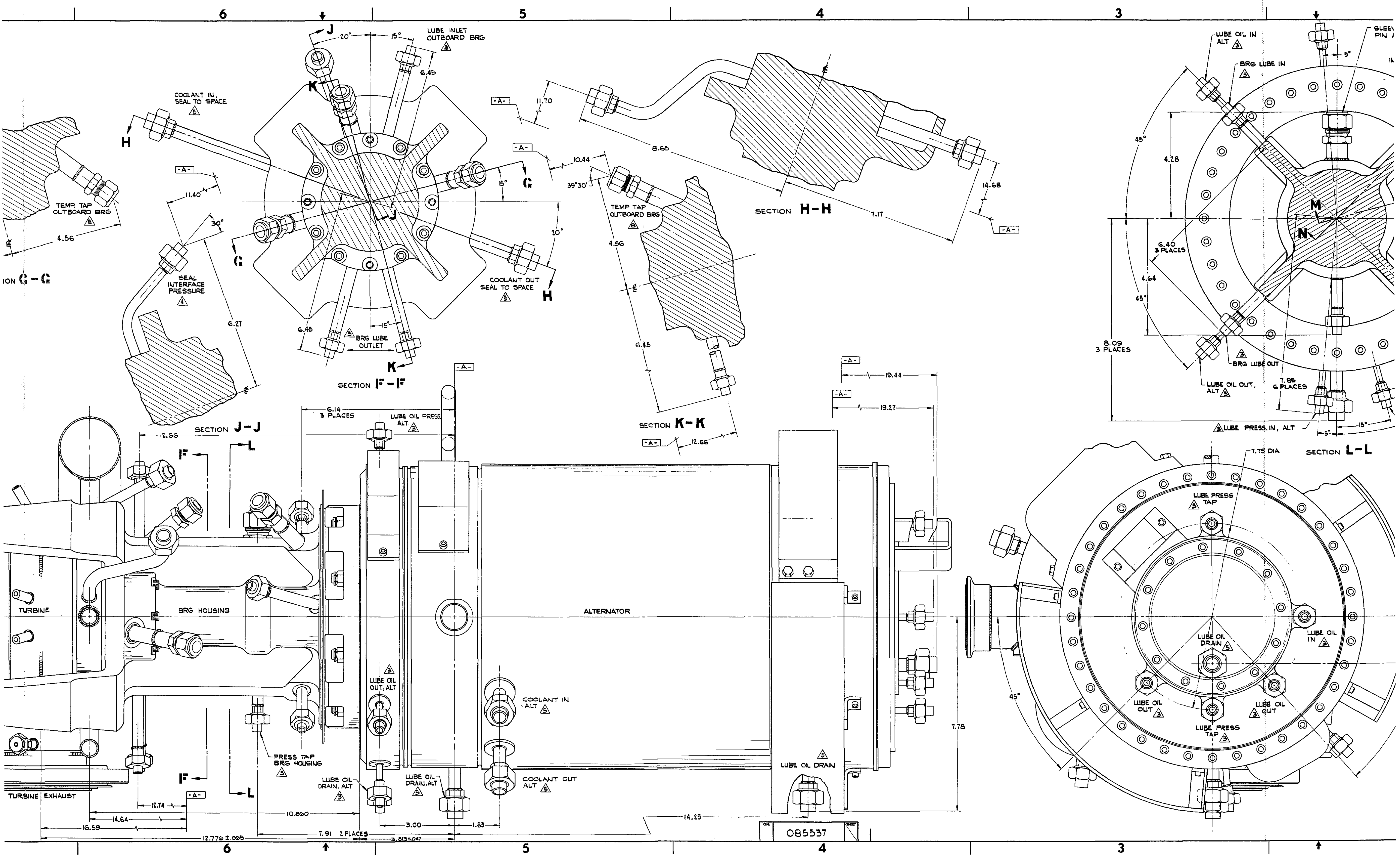
1. ALL DIMENSIONS TAKEN FROM [-A-], (TRUNNION BOSS ON ALTERNATOR) AND FROM ℄ OF TURB/ALT ASSY WITH THE EXCEPTION OF SECTION E-E.
2. INTERPRET DWG PER STANDARDS PRESCRIBED IN MIL-D-70327.

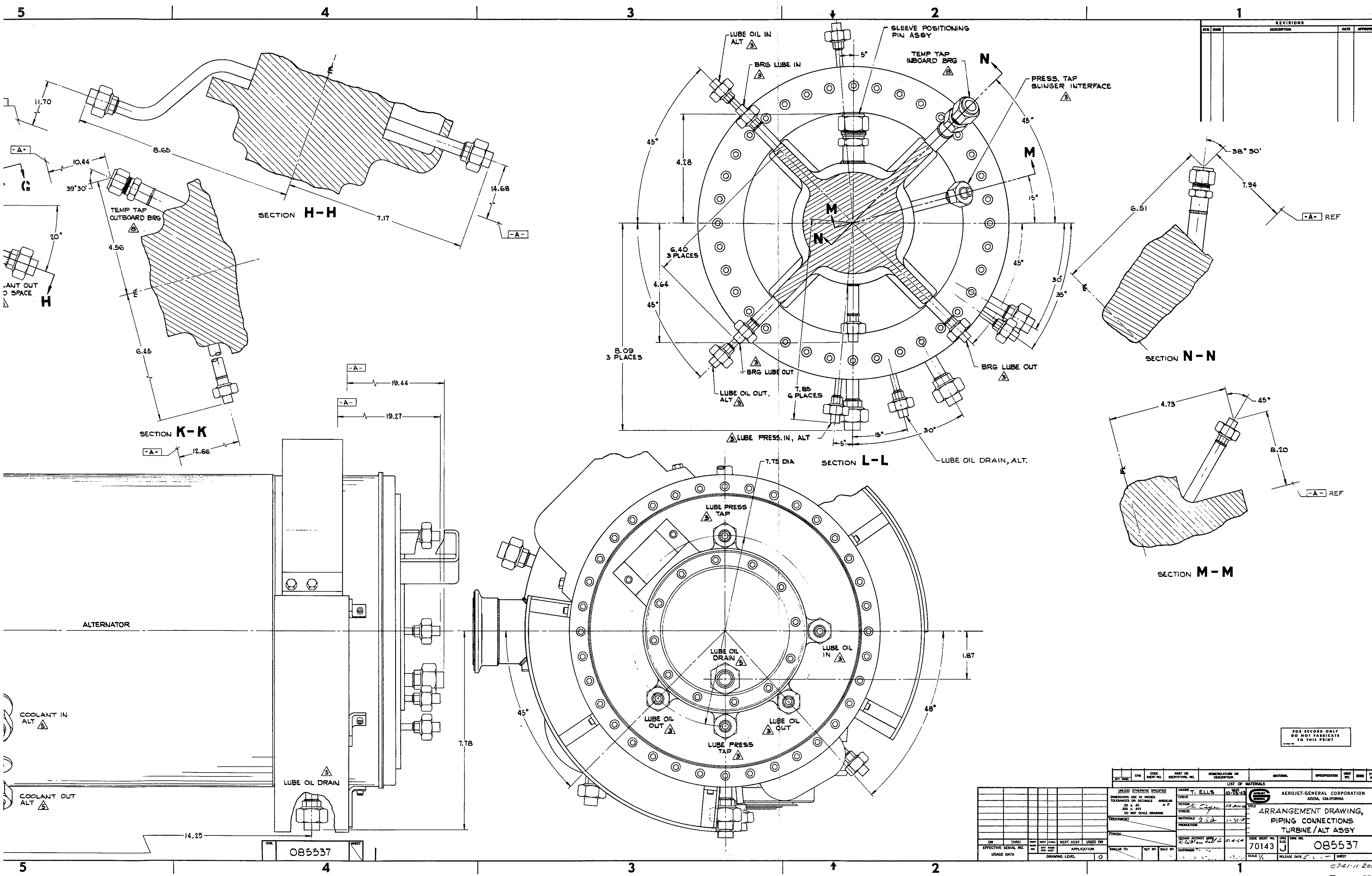
△3 CONOSEAL UNION FITTING NO. 54857-4 CODE IDENT NO. 98625. (REF)
△4 CONOSEAL UNION FITTING NO. 54857-6 CODE IDENT NO. 98625. (REF)
△5 CONOSEAL UNION FITTING NO. 54857-8 CODE IDENT NO. 98625. (REF)
△6 CONOSEAL TUBE JOINT NO. 50889-250S CODE IDENT NO. 98625. (REF)
△7 SWAGELOK CONNECTOR NO. 200-1-2W-316BT CODE IDENT NO. 02570. (REF)
△8 SWAGELOK CONNECTOR NO. 810-1-6W-316 BT CODE IDENT NO. 02570. (REF)
△9 SWAGELOK CONNECTOR NO. 200-R-6-316BT CODE IDENT NO. 02570 (REF)



SECTION B-B




SECTION G-G
TEMP. TAP OUTBOARD BRG
COOLANT IN, SEAL TO SPACE
SEAL INTERFACE PRESSURE
LUBE INLET OUTBOARD BRG
BRG LUBE OUTLET
COOLANT OUT SEAL TO SPACE
SECTION F-F
SECTION J-J
SECTION H-H
SECTION K-K
TEMP TAP OUTBOARD BRG
LUBE OIL IN ALT
BRG LUBE IN
BRG LUBE OUT
LUBE OIL OUT, ALT
LUBE PRESS. IN, ALT
SECTION L-L
7.75 DIA
LUBE PRESS TAP
LUBE OIL DRAIN
LUBE OIL IN
LUBE OIL OUT
TURBINE
BRG HOUSING
ALTERNATOR
LUBE OIL PRESS. ALT
LUBE OIL OUT, ALT
COOLANT IN ALT
COOLANT OUT ALT
LUBE OIL DRAIN
PRESS TAP BRG HOUSING
LUBE OIL DRAIN, ALT
TURBINE EXHAUST
085537
2

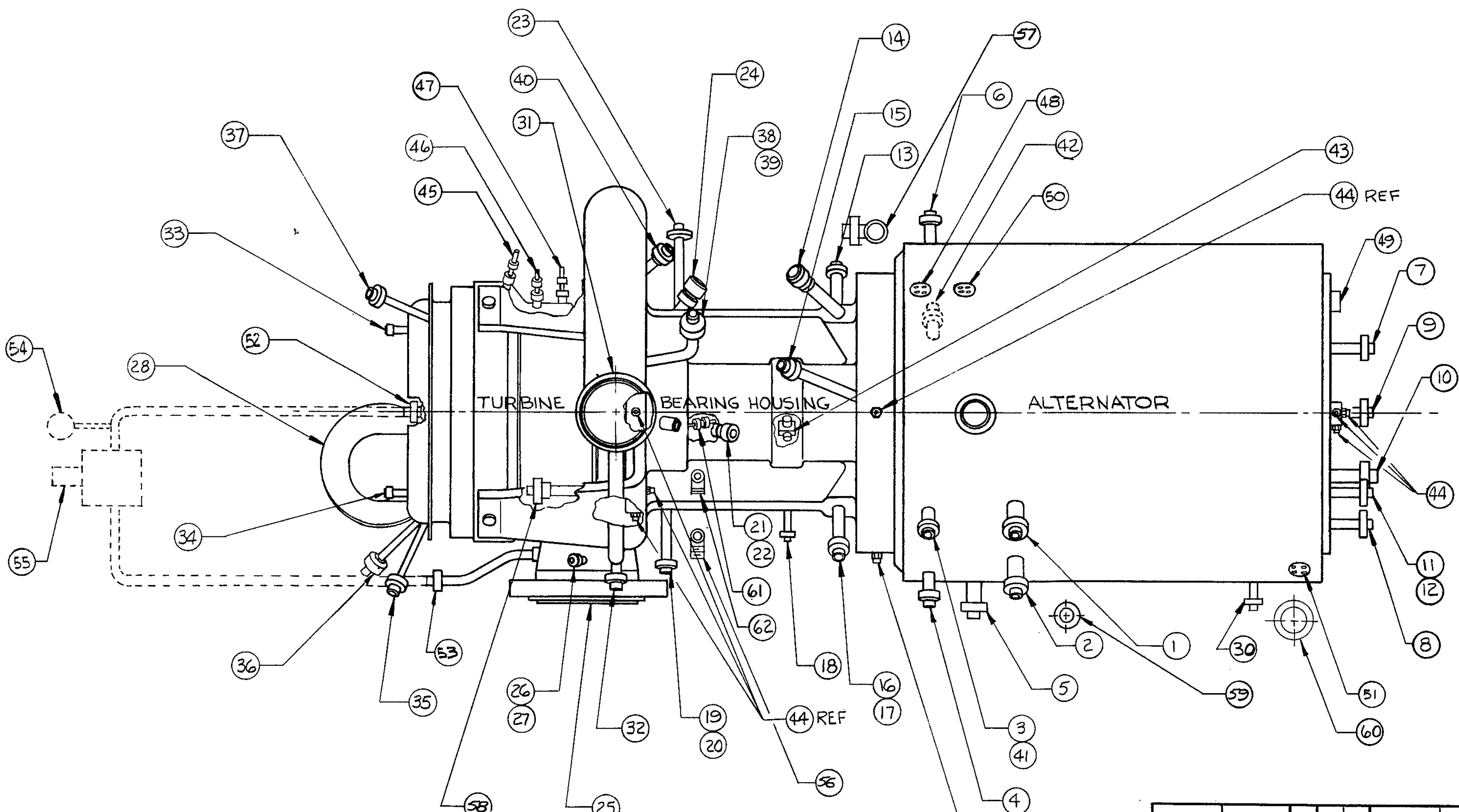

SECTION H-H
SECTION K-K
SECTION L-L
SECTION N-N
SECTION M-M
TEMP TAP OUTBOARD BRG
LUBE OIL IN ALT
BRG LUBE IN
SLEEVE POSITIONING PIN ASBY
TEMP TAP INBOARD BRG
PRESS. TAP SLINGER INTERFACE
BRG LUBE OUT
LUBE OIL OUT, ALT
LUBE PRESS. IN, ALT
LUBE OIL DRAIN, ALT.
7.75 DIA
LUBE PRESS TAP
LUBE OIL IN
LUBE OIL DRAIN
LUBE OIL OUT
ALTERNATOR
COOLANT IN ALT
COOLANT OUT ALT
LUBE OIL DRAIN
FOR RECORD ONLY DO NOT FABRICATE TO THIS PRINT
REVISIONS
LIST OF MATERIALS
AEROJET-GENERAL CORPORATION AZUSA, CALIFORNIA
ARRANGEMENT DRAWING, PIPING CONNECTIONS TURBINE/ALT ASSY
DRAWN T. ELLS
70143 J 085537
085537

2

ITEM NO.	TUBE SIZE	TYPE OF FITTING	PART NO.	DESCRIPTION
62	1/2	AN CROSS	AN827-8S	TURB HEAT EXCHANGER COOLANT INLET PRESS.
61	1/16 1/8	SWAGELOK	200-6-1-316	LIFT-OFF SEAL N_2 PRESSURE CONNECTION
60	1.00	CONOSEAL	54857-16	ALT DRAIN MANIFOLD CONNECTION
59	3/4	CONOSEAL	54857-12	LUBE/COOLANT OUTLET CONN
58	3/4	CONOSEAL	54857-12	LUBE/COOLANT INLET CONN
57	1/4	CONOSEAL	54857-4	LUBE PRESSURE, BRG INLET MANIFOLD
56	1/2	AN TEE	AN824-8	COOLANT PRESSURE, ALTERNATOR INLET
55	/	LESLIE DIAPHRAGM	MOD D-187971	VALVE-BALANCE PRESSURE CONTROL.
54	1/2	TRANSDUCER	~	THRUST BALANCE PRESSURE
53	1.00	CONOSEAL	54857-8	BYPASS TUBE, THRUST BALANCING, TURB. EXHAUST END
52	1.00	CONOSEAL	54857-8	BYPASS TUBE, THRUST BALANCING, TURB. INLET END
51	–	C.A.THERMOC	~	ANTI-DRIVE END WINDING TEMPERATURE ~ ALT.
50	–	C.A.THERMOC	~	DRIVE END WINDING TEMPERATURE ~ ALT.

ITEM NO.	TUBE SIZE	TYPE OF FITTING	PART NO.	DESCRIPTION
49	–	C.A.THERMOC	~	ANTI-DRIVE END BRG TEMPERATURE ~ ALT.
48	–	C.A.THERMOC	~	DRIVE END BRG TEMPERATURE ~ ALT.
47	1/4	AGC	0939685	4TH STAGE NOZZLE INLET PRESSURE TAP
46	1/4	AGC	0939683	3RD STAGE NOZZLE INLET PRESSURE TAP
45	1/4	AGC	093968-1	2ND STAGE NOZZLE INLET PRESSURE TAP
44	–	ENDEVCO	MODEL 2235C	ACCELEROMETER ~ 8 REQD
43	–	A.G.C	E100806	TRANSDUCER ASSY, SHAFT POSITION ~ FAR SIDE
42	1/4	CONOSEAL	54857-4	LUBE OIL "IN" FAR SIDE ~ ALTERNATOR
41	1/4	CONOSEAL	54857-4	LUBE OIL "OUT" FAR SIDE ~ ALTERNATOR
40	3/8	CONOSEAL	54857-6	SEAL INTERFACE PRESSURE
39	1/2	CONOSEAL	54857-8	COOLANT "OUT" SEAL TO SPACE ~ FAR SIDE
38	1/2	CONOSEAL	54857-8	COOLANT "IN" SEAL TO SPACE ~ NEAR SIDE
37	1/4	CONOSEAL	54857-4	1ST STAGE NOZZLE OUTLET PRESSURE ~ TAP
36	1/4	CONOSEAL	54857-4	1ST STAGE NOZZLE OUTLET PRESSURE ~ TAP

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED
A		SEE A CHG DCN	10-23-64	



ITEM NO.	TUBE SIZE	TYPE OF FITTING	PART NO.	DESCRIPTION
35	1/4	CONOSEAL	54857-4	TURBINE INLET MANIFOLD PRESSURE
34	1/8	SWAGELOK	200-1-2W-316BT	TURBINE INLET TEMPERATURE THERMOCOUPLE
33	1/8	SWAGELOK	200-1-2W-316BT	TURBINE INLET TEMPERATURE THERMOCOUPLE
32	3/8	CONOSEAL	54857-6	DRAIN SEAL VENT MANIFOLD
31	2 1/2	CONOSEAL	50889-250-5	OUTLET SEAL VENT MANIFOLD
30	1/2	CONOSEAL	54857-8	LUBE OIL DRAIN ~ ALTERNATOR
29	1/4	CONOSEAL	54857-4	LUBE OIL PRESSURE-ALTERNATOR ~ FAR SIDE
28	1 3/4	CONOSEAL	092045-1	TURBINE INLET FLANGE
27	1/8	SWAGELOK	200-R-6-316	TURBINE EXHAUST TEMPERATURE ~ NEAR SIDE
26	3/8	CONOSEAL	54857-6	TURBINE EXHAUST PRESSURE ~ FAR SIDE
25	3 5/8	CONOSEAL	092182-3	TURBINE EXHAUST FLANGE
24	1/2	SWAGELOK	810-1-6W-316BT	THERMOCOUPLE, OUTBOARD BEARING
23	1/4	CONOSEAL	54857-4	BEARING LUBE INLET, INBOARD
22	1/2	SWAGELOK	810-1-6W-316BT	THERMOCOUPLE OUTBOARD BEARING - FAR SIDE
21	1/2	SWAGELOK	810-1-6W-316BT	THERMOCOUPLE OUTBOARD BEARING - NEAR SIDE
20	1/4	CONOSEAL	54857-4	BEARING LUBE OUTLET - TURBINE - FAR SIDE
19	1/4	CONOSEAL	54857-4	BEARING LUBE OUTLET - TURBINE - NEAR SIDE
18	1/4	CONOSEAL	54857-4	PRESSURE TAP BRG. HOUSING
17	1/4	CONOSEAL	54857-4	BEARING LUBE OUTLET - FAR SIDE
16	1/4	CONOSEAL	54857-4	BEARING LUBE OUTLET ~ NEAR SIDE
15	1/4	CONOSEAL	54857-4	PRESSURE TAP - SLINGER INTERFACE
14	1/2	SWAGELOK	810-1-6W-316BT	THERMOCOUPLE ~ INBOARD BEARING
13	1/4	CONOSEAL	54857-4	BEARING LUBE INLET FAR SIDE
12	1/4	CONOSEAL	54857-4	LUBE OIL OUT FAR SIDE ~ ALTERNATOR
11	1/4	CONOSEAL	54857-4	LUBE OIL OUT NEAR SIDE ~ ALTERNATOR
10	1/2	CONOSEAL	54857-8	LUBE OIL DRAIN ~ ALTERNATOR
9	1/4	CONOSEAL	54857-4	LUBE OIL "IN" FARSIDE ~ ALTERNATOR
8	1/4	CONOSEAL	54857-4	LUBE PRESSURE TAP (INST) ~ ALTERNATOR
7	1/4	CONOSEAL	54857-4	LUBE PRESSURE TAP (INST) ~ ALTERNATOR
6	1/4	CONOSEAL	54857-4	LUBE OIL PRESS. ALTERNATOR
5	1/2	CONOSEAL	54857-8	LUBE OIL DRAIN ~ ALTERNATOR
4	1/4	CONOSEAL	54857-4	LUBE OIL "OUT" NEAR SIDE ~ ALTERNATOR
3	1/4	CONOSEAL	54857-4	LUBE OIL "OUT" NEAR SIDE ~ ALTERNATOR
2	1/2	CONOSEAL	54857-8	COOLANT "OUT" ~ ALTERNATOR
1	1/2	CONOSEAL	54857-8	COOLANT "IN" ~ ALTERNATOR

QTY REQD	SYM	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT.	ZONE	ITEM NO.

LIST OF MATERIALS

NOTES:
3. PIPING & INSTRUMENTATION NOTED APPLICABLE TO TURBINE ALTERNATOR P/N 093000-5 ONLY.
2. FOR INSTRUMENTATION INSTALLATION SEE DWG 094753-5.
1. FOR DETAILED PIPING & INSTRUMENTATION CONNECTIONS SEE DWG 085537.

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON DECIMALS .XX ± .03 .XXX ± .010 ANGULAR ± 2°
DO NOT SCALE DRAWING
TREATMENT
FINISH

				FINAL	AGAN-0010
ON	THRU	PART DASH NO.	NEXT / QTY REQD PER ASSY	NEXT ASSY	USED ON
EFFECTIVE SERIAL NO.				APPLICATION	
USAGE DATA		DRAWING LEVEL			O

DRAWN P. BECK DATE 8-4-64
CHECK —
DESIGN J.H. Callahan 8-4-64
STRESS
MATERIALS —
PRODUCTION —
DESIGN ACTIVITY APPD 8/7/64
CUSTOMER —
SIMILAR TO: 093987
ACT WT | CALC WT

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

TITLE PIPING & INSTRUMENTATION DIAGRAM-TAA

CODE IDENT NO. 70143 | DWG SIZE D | DWG NO. 096040
SCALE NONE | RELEASE DATE 8-17-64 | SHEET

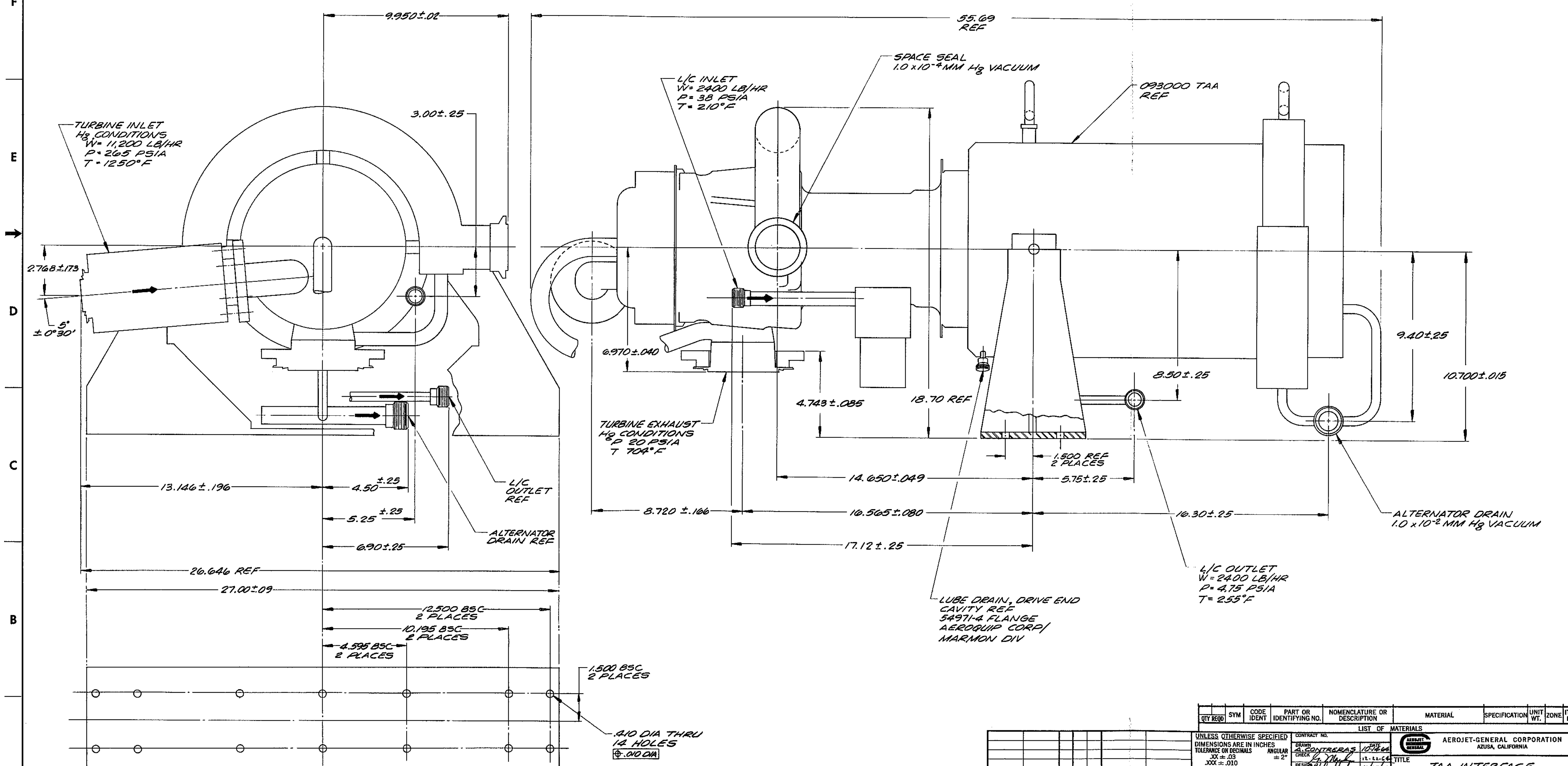
COPY 096040 A

DIETERICH-POST CLEARPRINT 1020 81-067-013 REV. 9-62

NOTES: 1. REMOVE ALL BURRS AND SHARP EDGES
2. INTERPRET DRAWING PER STANDARDS PRESCRIBED IN MIL-D-70327.
3 TURBINE INLET ALLOWABLE LOADS PREDICATED ON APPLIED BENDING MOMENT SPECIFIED.
4 ALLOWABLE LOADS SPECIFIED ARE SEPARATELY APPLIED.

TAA INTERFACE CONNECTION DATA

	LOCATION	TUBE O.D.	CONNECTION	ALLOWABLE FLANGE LOADS AXIAL FORCE	RADIAL FORCE	BENDING MOMENT	TORSION
3	TURBINE INLET	1.75	095314 FILTER	52 LB	37 LB	80 FT LB	1 FT LB
4	L/C INLET	.75	54971-12 FLANGE AEROQUIP CORP/ MARMON DIV	50 LB	50 LB		
	L/C OUTLET	.75	54971-12 FLANGE AEROQUIP CORP/ MARMON DIV				
	ALTERNATOR DRAIN	1.00	54971-16 FLANGE AEROQUIP CORP/ MARMON DIV				
4	SPACE SEAL	2.50	50889-250-5 FLANGE AEROQUIP CORP/ MARMON DIV	270 LB	67 LB	77 FT LB	40 FT LB
4	TURBINE EXHAUST	3.62	092046	10 LB	50 LB	28 FT LB	



REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCE ON DECIMALS .XX ± .03 .XXX ± .010 ANGULAR ± 2° DO NOT SCALE DRAWING

TREATMENT

FINISH

SIMILAR TO

LIST OF MATERIALS

AEROJET-GENERAL CORPORATION AZUSA, CALIFORNIA

TITLE TAA INTERFACE ARRANGEMENT -1 MODEL

DWG SIZE E | CODE IDENT NO. 70143 | DWG NO. 094944

SCALE NONE | RELEASE DATE 12-28-64 | SHEET

0741-11

COPY

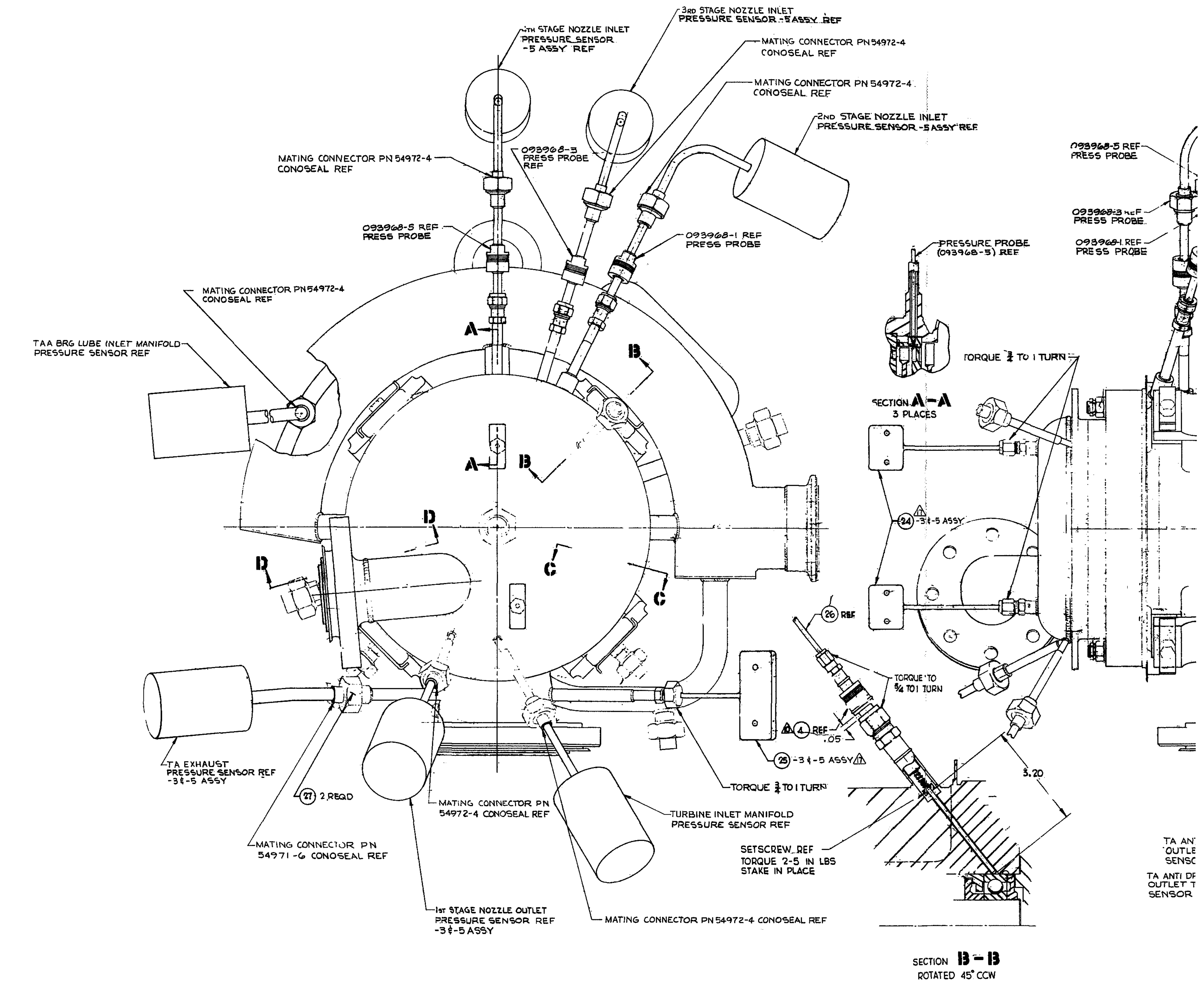
094944

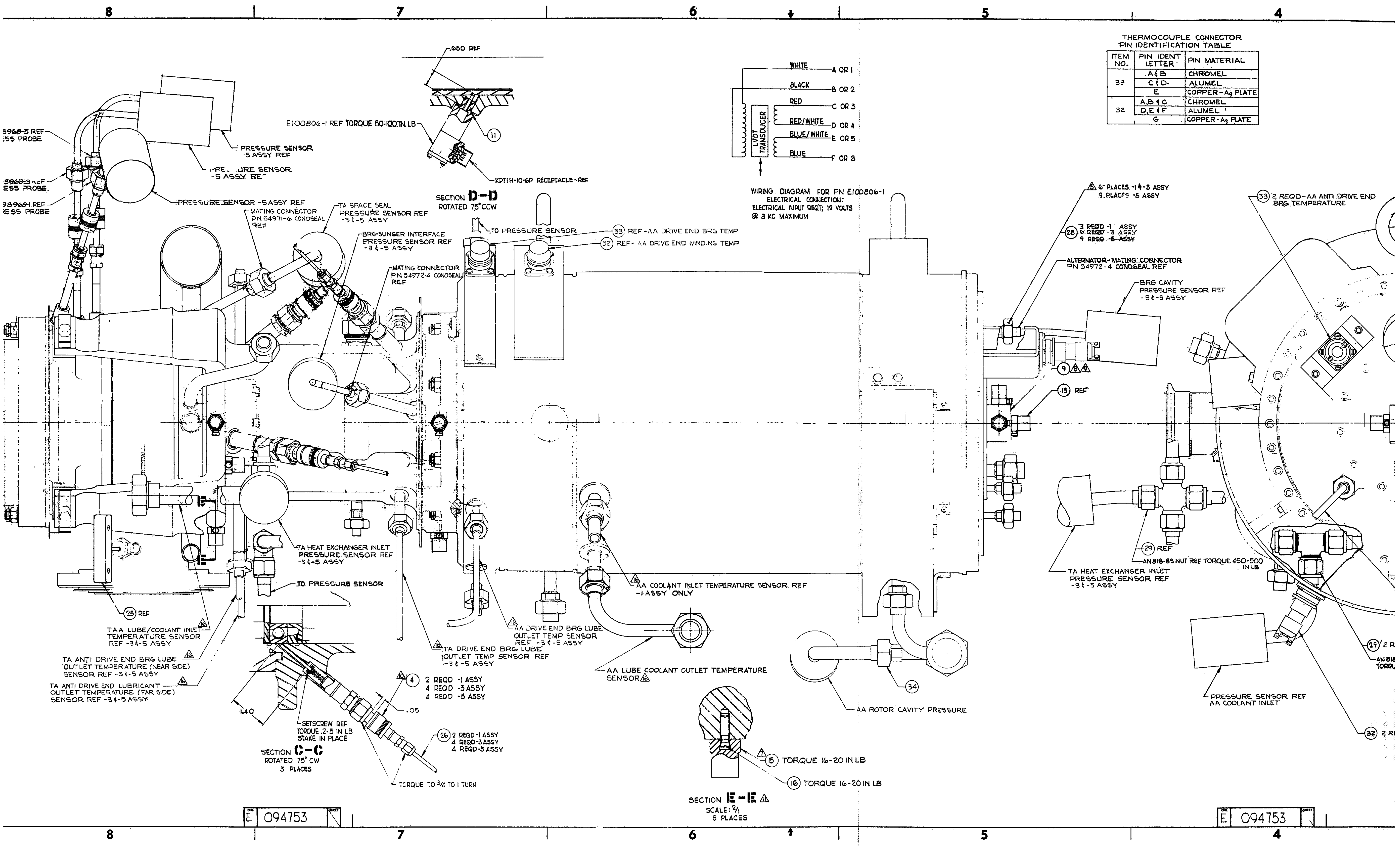
NOTES:

1. INTERPRET DRAWING PER STANDARDS PRESCRIBED IN MIL-D-70327
2. WHEN MAKING OR BREAKING TUBE CONNECTIONS, DO NOT TORQUE AGAINST WELD JOINTS.
3. ITEMS 27,28,29 & 34 MUST BE REPLACED AT EACH ASSEMBLY BUILDUP IF GASKETED JOINT IS DIS-ASSEMBLED.
4. EXERCISE CARE WHILE MAKING OR BREAKING TUBE CONNECTIONS TO PREVENT ENTRANCE OF FOREIGN MATTER INTO INTERIOR PASSAGES.
5. TORQUE CONOSEAL TUBE CONNECTIONS AS FOLLOWS.

.250 CONNECTIONS	160-240 IN LB
.375 CONNECTIONS	270-400 IN LB
.500 CONNECTIONS	400-600 IN LB

6. REMOVED
7. APPLY FILM OF ITEM 35 OIL TO ITEM 15 MOUNTING SURFACE BEFORE INSTALLATION PER SECTION E-E.
8. APPLY .04 THICK COAT OF ITEM 31 CEMENT & LIQUID MIXTURE TO MOUNTING SUFACE OF ITEM 9.
9. BEFORE MOUNTING ITEM 9 TO ALTERNATOR, INSTALL ITEM 15 THREE PLACES PER SECTION E-E.
10. BEARING THERMOCOUPLE ASSEMBLY AND INSTALLATION PROCEDURE:
    a. LOCATE COLLAR ON ITEM 26 TO DIMENSION SHOWN AND LOCK IN PLACE.
    b. ASSEMBLE THERMOCOUPLE BODY ASSEMBLY AND SPRING INTO ITEM 26 AND COMPRESS SPRING VIA BODY ASSEMBLY TO .05 DIM.
    c. TORQUE LOWER SWAGELOK NUT TO LOCK BODY ASSY IN PLACE.
    d. TORQUE UPPER SWAGELOK NUT.
    CAUTION - REFER TO GENERAL NOTE 2.
11. ALL INSTRUMENTATION EXCEPT ITEM 15 SHALL BE INSTALLED IN THE SNAP-8 CLEAN ROOM PRIOR TO FINAL TAA HELIUM LEAK TEST.
12. PRESSURE TRANSDUCERS TO BE SUPPLIED WITH TUBE EXTENSION AND FITTING CONNECTIONS AS REQUIRED FOR PROPER TAA INSTALLATION.
13. REMOVED
14. ANGULAR POSITION OF PRESSURE SENSORS TO BE 5° TO 15° BELOW HORIZONTAL PLANE. BEND SENSOR TUBE STUBS PER MS 33611.
15. SOURCE OF SUPPLY:
    GUGGENHEIMER BROS DENTAL CO., LOS ANGELES, CALIF.
16. INSTALL TEMPERATURE SENSORS PER AGC DWG NO. 096305.
17. INSTALL ITEMS 24 & 25 PER AGC DWG NO. E101081





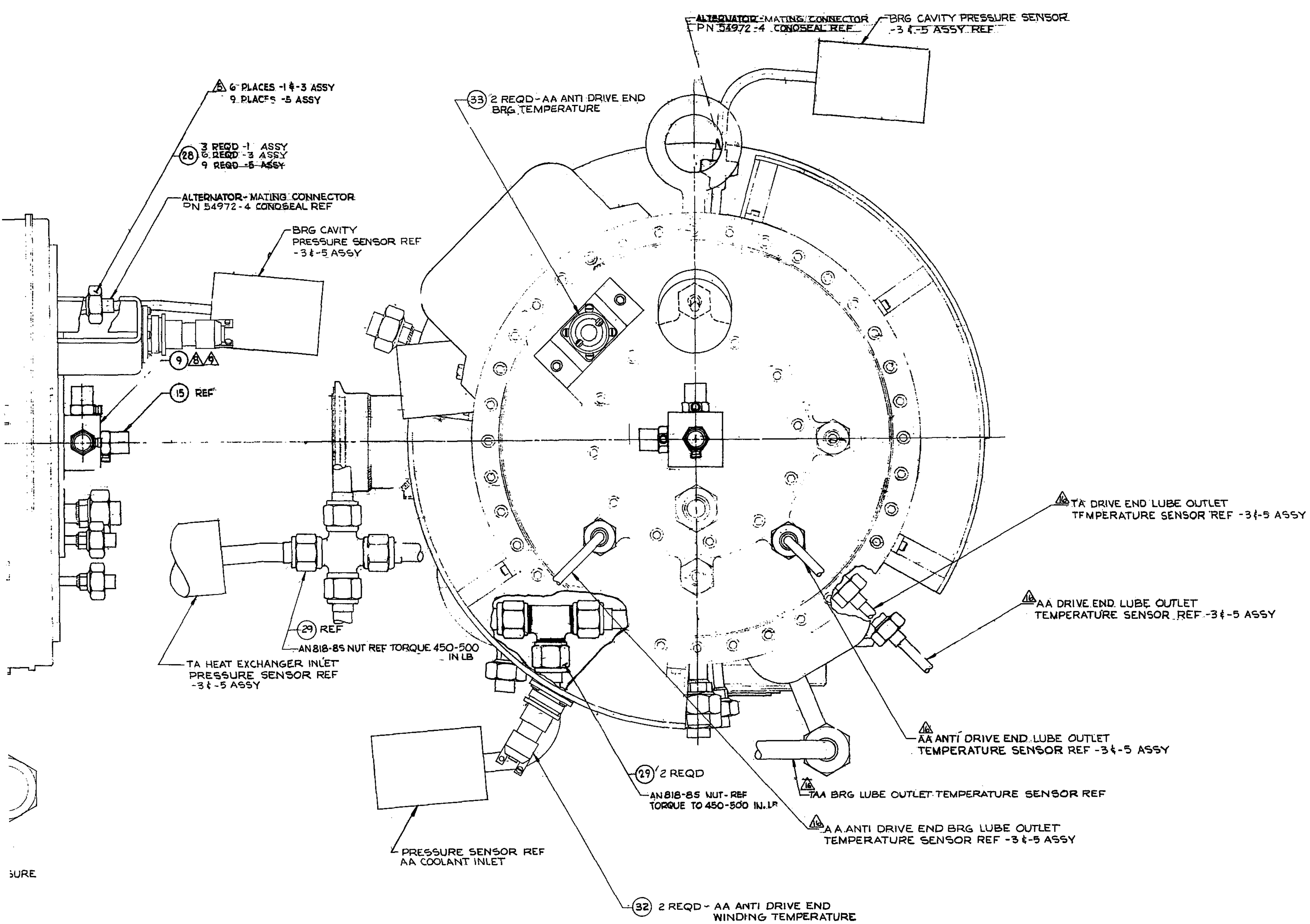
THERMOCOUPLE CONNECTOR PIN IDENTIFICATION TABLE

ITEM NO.	PIN IDENT LETTER	PIN MATERIAL
33	A & B	CHROMEL
	C & D	ALUMEL
	E	COPPER-Ag PLATE
32	A, B & C	CHROMEL
	D, E & F	ALUMEL
	G	COPPER-Ag PLATE

REV	ZONE	DESCRIPTION	DATE	APPROVED
E		REDRAWN WITH CHANGES REPLACES 094753 "D" CHANGE		

THERMOCOUPLE CONNECTOR PIN IDENTIFICATION TABLE

ITEM NO.	PIN IDENT LETTER	PIN MATERIAL
33	A & B	CHROMEL
	C & D	ALUMEL
	E	COPPER-Ag PLATE
32	A, B & C	CHROMEL
	D, E & F	ALUMEL
	G	COPPER-Ag PLATE



-5	-3	-1	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	ZONE	ITEM NO.
AR	AR	AR			LUBRICANT		MIL-L-644		35
1	1	1	98625	54973-85	GASKET			5A	34
2	2	2	93428	10-410797 -5P	PLUG			4D	33
2	2	2	93428	10-410795 -1P	PLUG			4A	32
AR	AR	AR			BIGCAST DENTAL CEMENT & LIQUID	COML GRADE			31
					REMOVED				30
2	2	2	01673	AP50C-8	SEAL			4A	29
9	6	3	98625	54973-45	GASKET			5C	28
2	2	2	98625	54973-65	GASKET			10B	27
4	4	2	15260	316-125-K-10-U-PK-JK	THERMOC PROBE			7A	26
1	1		15260	316-125-K-9-U-PK-JK	THERMOC PROBE			9B	25
2	2		15260	316-125-K-6-U-PK-JK	THERMOC PROBE			9C	24
					REMOVED				23
									22
									21
									20
									19
									18
					REMOVED				17
8	8	8	95411	2981-1	STUD			6A	16
8	8	8	95411	2235C	ACCELEROMETER			6A	15
					REMOVED				14
					REMOVED				13
									12
1	1	1		NAS-1593 -016	O-RING			7D	11
									10
1	1	1		094926-1	BOSS			5C	9
					REMOVED				8
					REMOVED				7
					REMOVED				6
					REMOVED				5
4	4	2		093087-1	THERMOCOUPLE ASSY			7A	4
									3
									2
									1

LIST OF MATERIALS

-5	FINAL	AGAN-0010	
-3	FINAL	AGAN-0010	
-1	FINAL	AGAN-0010	
PART NO.	NEXT ASSY	USED ON	
EFFECTIVE SERIAL NO. USAGE DATA	APPLICATION		DRAWING LEVEL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS .XX ± .03 .XXX ± .010 ANGULAR ± 2° DO NOT SCALE DRAWING

DRAWN L. HEDRICK

AEROJET-GENERAL CORPORATION AZUSA, CALIFORNIA

INSTRUMENTATION INSTALLATION, TAA

CODE IDENT NO.	DWG SIZE	DWG NO.
70143	J	094753

SCALE AS NOTED

E 094753

COPY 094753 E

Page VI-8

3

AEROJET
GENERAL TIRE
GENERAL

AEROJET-GENERAL CORPORATION